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August 1993

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Scour Protection for Dam No. 2, Arkansas River, Arkansas

Hydraulic Model Investigation

by John E. Hite, Jr.
Hydraulics Laboratory

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Prepared for U.S. Army Engineer District, Little Rock

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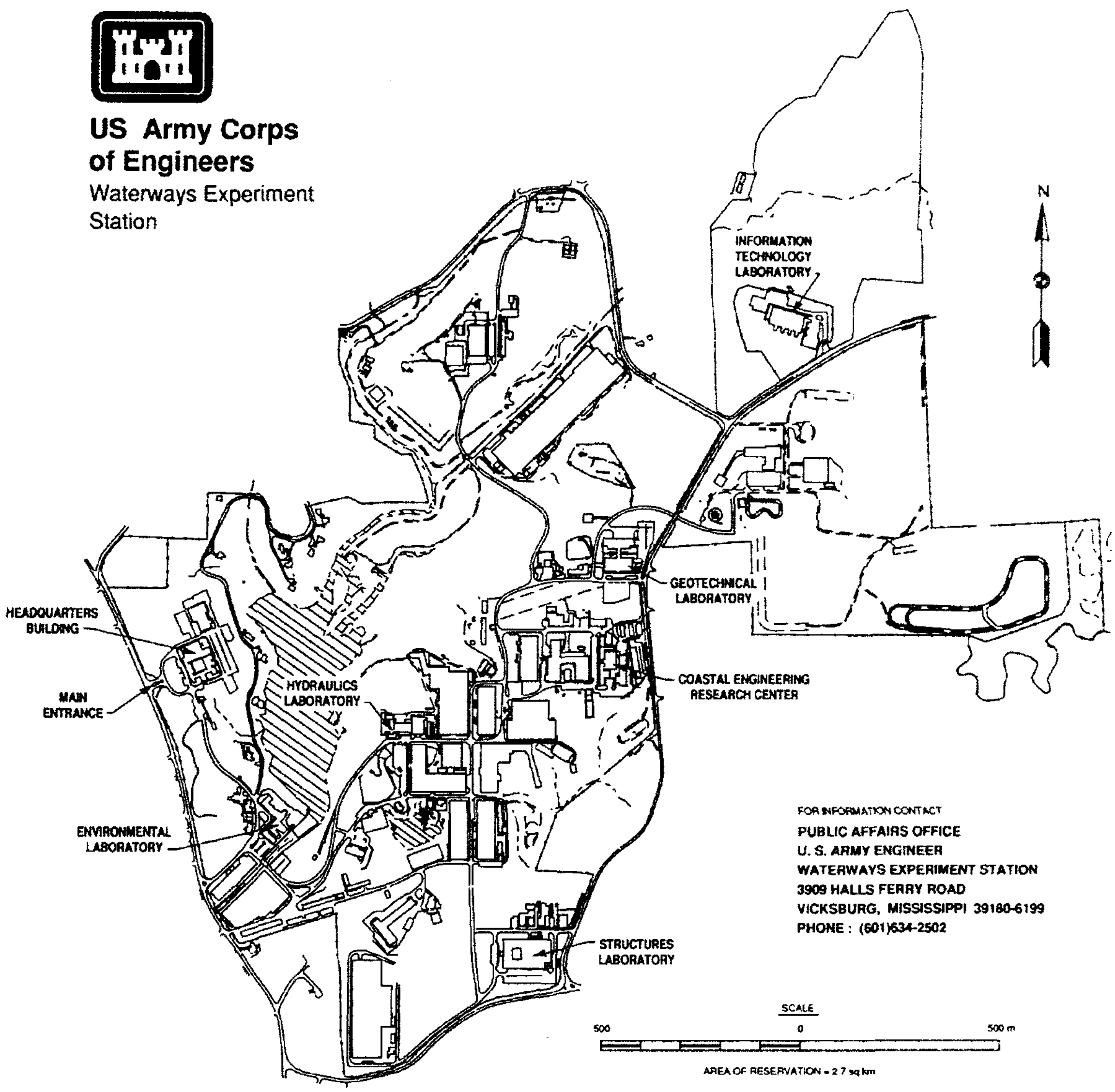

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Contents

Preface

The model investigations reported herein were authorized by the Headquarters, US Army Corps of Engineers (USACE), on 10 September 1984 at the request of the US Army Engineer District, Little Rock (SWL). The studies were conducted by personnel of the Hydraulics Laboratory, US Army Engineer Waterways Experiment Station (WES), during the period April 1985 to October 1987. All studies were conducted under the direction of Messrs. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory, J. L. Grace, Jr., former Chief of the Hydraulic Structures Division, and G. A. Pickering, Chief of the Hydraulic Structures Division. The tests were conducted by Messrs. T. E. Murphy, Jr., M. P. Thomas, J. E. Davis, and J. E. Hite, Jr., Locks and Conduits Branch, under the supervision of Mr. J. F. George, Chief of the Locks and Conduits Branch. This report was prepared by Mr. Hite and edited by Mrs. M. C. Gay, Information Technology Laboratory, WES.

The model structure was fabricated by Messrs. E. A. Case and L. B. Storey under the supervision of Mr. S. J. Leist; and model construction was performed by Messrs. C. L. Brown, A. J. Lee, W. R. Patterson, A. L. Harris, W. C. Thomas, A. Taylor, E. Jorden, V. Copeland, S. W. Sennett, M. W. Keene, and E. C. Rhodman, under the supervision of Mr. M. J. Wooley, all of the Engineering and Construction Services Division.

Mr. B. McCartney, USACE; Messrs. T. Coomes, D. Brown, J. Smith, T. Schmidgall, and A. D. Denys of the US Army Engineer Division, Southwestern (SWD); Messrs. G. Wilbur, J. Baker, L. Pope, D. Mills, G. Raible, J. Martin, S. Brewer, R. Shelden, M. Willis, T. Cook, J. Woolfolk, A. Austin, D. Reeves, and H. Hammersla, SWL; COL Wayne Whitehead, EN, former Commander, SWL; COL Anthony V. Nida, EN, Commander, SWD; and MG Jerome B. Hilmes, Commander, SWD, visited WES during the study to discuss test results and to correlate these results with concurrent design work.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter

1 Introduction

Prototype

Dam No. 2 is located at mile 40.5 (1943 survey) on the Arkansas River in Arkansas and Desha Counties, Arkansas (Figure 1). It is the first of a series of locks and dams on the Arkansas River and serves as the entrance for navigation between the Mississippi and Arkansas rivers.

The dam consists of a gated concrete spillway surmounted by 16 tainter gates (Plate 1), each 30 ft[1] high by 60 ft wide, with earth embankments on the abutments, and a hydraulic jump type stilling basin. Original scour protection consisted of a concrete scour slab and riprap upstream from the dam and graded riprap downstream from the stilling basin (Figure 2). The spillway and stilling basin were founded on concrete, timber, and steel piles. The project was constructed in a man-made cutoff between two bends in the river channel and cofferdams were not required.

Problem

Damage to the original scour protection has occurred several times since the project has been in operation. Bank failures on the left and right sides downstream from the structure occurred in 1969. Quarry-run stone was used to repair the damage. A diver's report in 1971 indicated scour had occurred immediately adjacent to the end sill in bays 2, 4, and 10 through 16. Riprap was also missing from the toe near piers 5, 11, 12, and 13. About 20 ft of the crown section near pier 12 had been displaced. Some of these areas were repaired with riprap. Another slide in the right bank revetment was also repaired in 1971. A severe slide developed in the left bank revetment and eroded approximately 140 ft of top bank in March 1973. This was repaired in an emergency contract. In August 1976, riprap was added to damaged areas found downstream from the stilling basin.

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[1] A table of factors for converting non-SI units of measurement to SI units is found on page v.

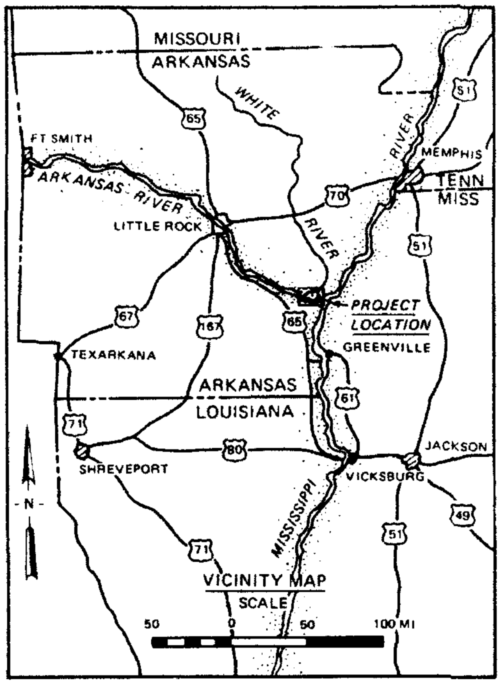


Figure 1. Vicinity map

In December 1982, 38 barges broke loose from their moorings upstream of Dam No. 2. Sixteen barges drifted into the dam and two barges subsequently sank against the spillway. Twelve of the sixteen gates were either partially or completely blocked as depicted in Figure 3. The discharge during this time varied from about 258,000 cfs to about 35,000 cfs. The maximum discharge through the open gates was estimated to be 39,400 cfs per gate, and because of the blockage, the upper pool was about 7 ft higher than for normal operation. The sunken barges, in addition to blocking flow, caused extreme turbulence and velocities both upstream and downstream from the dam. Extensive damage to the scour protection was caused by this extreme turbulence. The upstream scour protection stone and the concrete scour slab were destroyed from pier 3 to pier 10, a distance of about 480 ft. The stone protection downstream from the stilling basin was extensively damaged or completely destroyed in bay 7 and between piers 9 and 15. The remainder of the downstream stone protection received slight to moderate damage. The gates and the concrete portions of the structure also were damaged. Repairs were completed in July 1983 to ensure safe normal operating conditions at the project.

In addition to the scour protection problems experienced, the tailwater rating curve is expected to continue to lower. This is attributed to the shortening of the river (by about 6 miles) by constructing the dam in a manmade cutoff, no tailwater control since this is the last structure on the river, and a general lowering of stages on the Mississippi River that has been observed since 1930.

Purpose of the Model Study

Due to the history of costly repairs, lowering of the tailwater rating curve, and the possibility of abnormal operating conditions, there is concern over the safety of Dam No. 2. A model study was deemed necessary to verify the stability of the repairs made after the December 1982 barge accident under extreme operating conditions and to develop scour protection that would remain stable for flow conditions caused by a single gate fully open, a normal

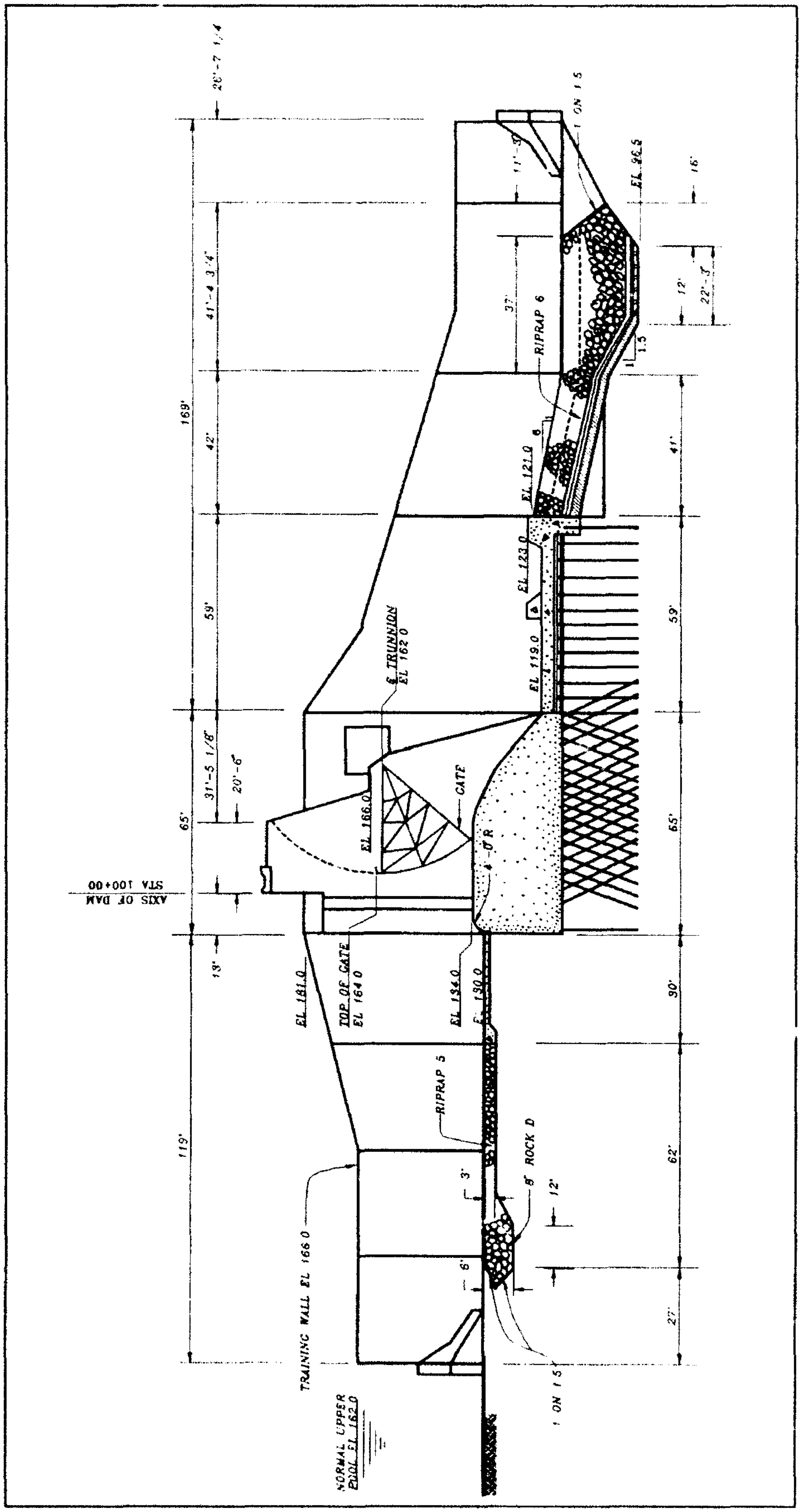


Figure 2. Section view of original structure

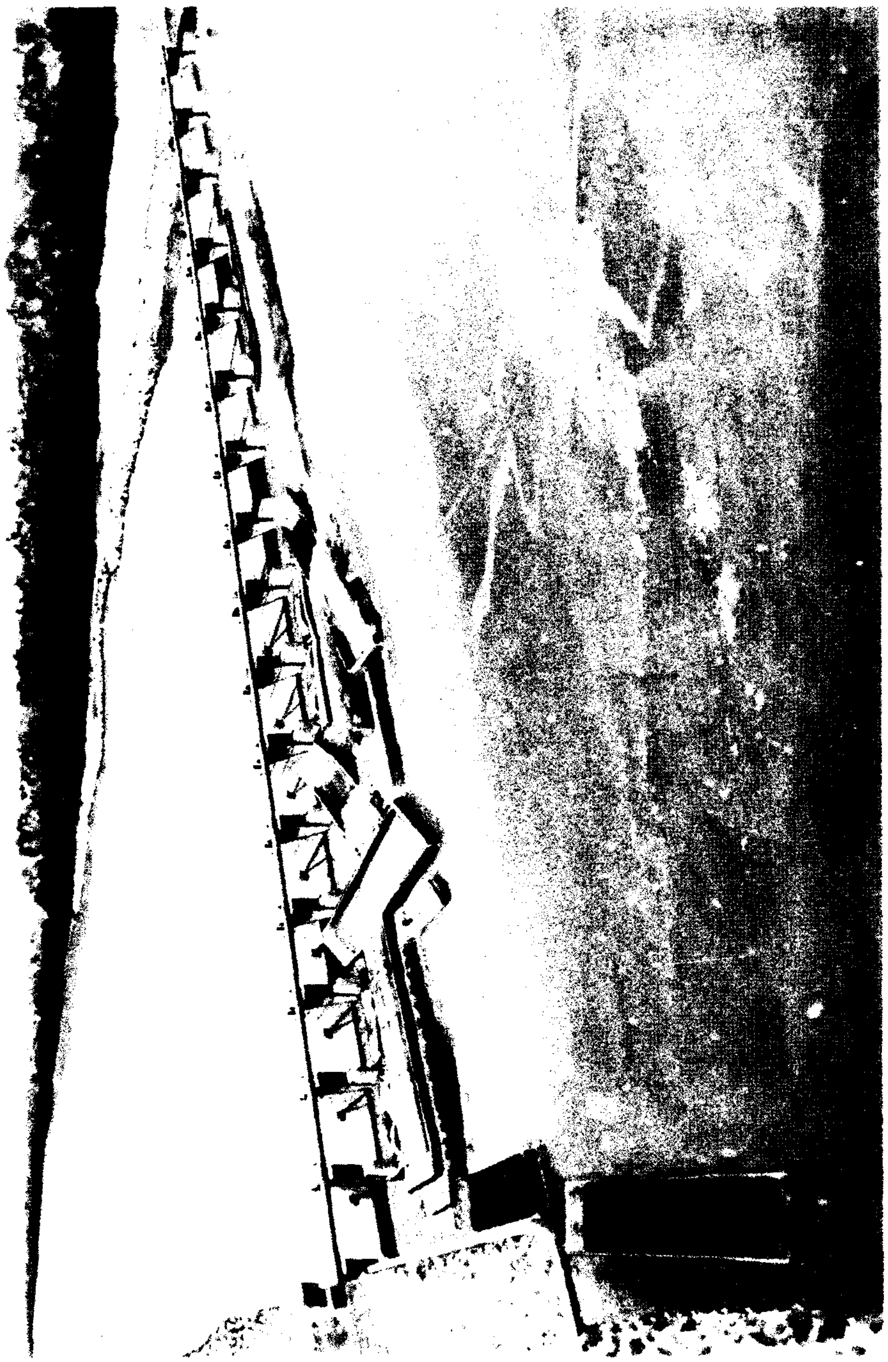


Figure 3. Artist's conception of barge accident

upper pool elevation of 162 ft,[1] and minimum projected tailwater. These conditions were considered representative of a severe abnormal operating condition. Also, the plan developed was to be tested with upper pool elevations higher than normal.

[1] All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

2 The Model

Description

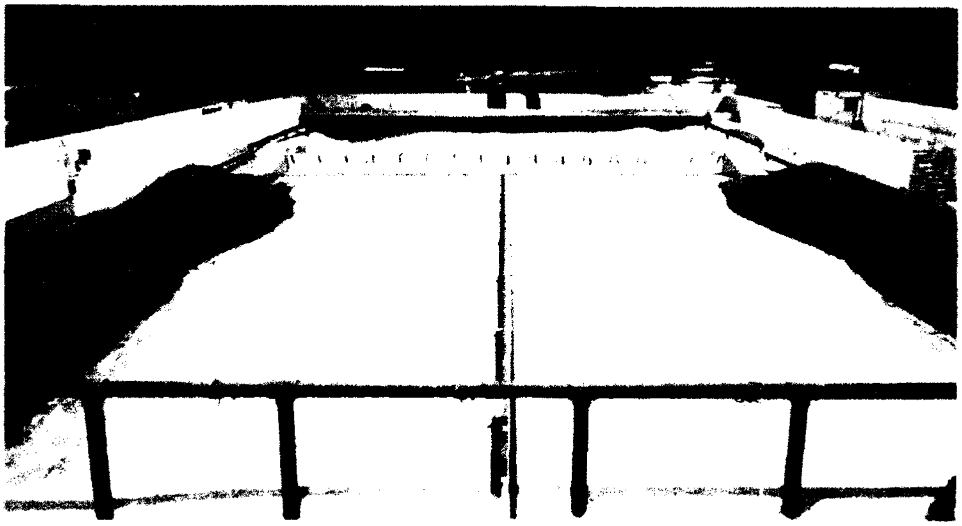
The model (Figure 4) was constructed to an undistorted scale of 1:36 and reproduced about 600 ft of topography upstream from the structure, the entire structure with 16 gates and stilling basin, the scour protection downstream, and approximately 1,200 ft of the exit channel. The structure was fabricated from sheet metal, and the stilling basin was constructed of plastic-coated plywood. The basin elements were constructed of wood and treated with a waterproofing compound to prevent swelling. A portion of the upstream topography was molded in sand and cement mortar to sheet metal templates, and the area immediately upstream from the dam was molded in riprap. The area immediately downstream from the dam was molded in riprap, and the remaining exit channel was molded in sand. A model layout is shown in Plate 1.

Model Appurtenances

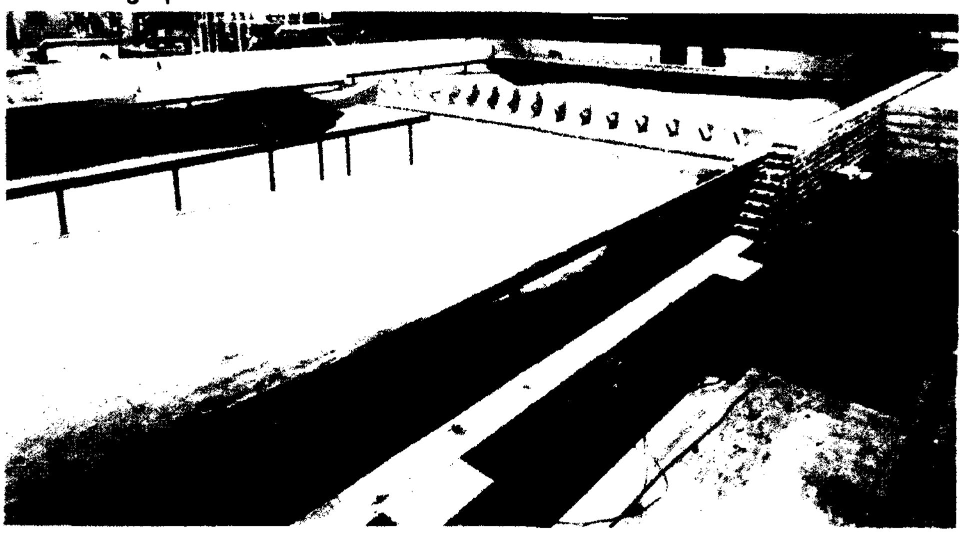
Water used in operation of the models was supplied by a circulating system. Discharges in the model, measured with venturi meters and flowmeters installed in the inflow lines, were baffled when entering the model. Water-surface elevations and soundings over the sand and riprap beds were measured with point gages. Velocities were measured with a pitot tube mounted to permit measurement of flow from any direction and at any depth. The tailwater in the lower end of the model was maintained at the desired depth by an adjustable tailgate. Different designs, along with various flow conditions, were recorded photographically.

Scale Relations

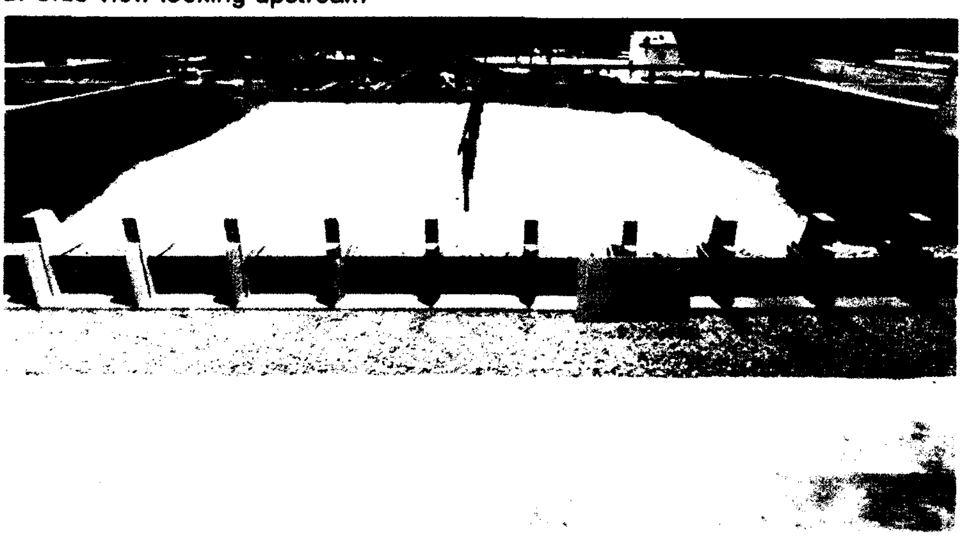
The accepted equations of hydraulic similitude, based on the Froudian criteria, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for the transference of model data to prototype equivalents are presented in the following tabulation:



a. Looking upstream



b. Side view looking upstream



c. Looking downstream

Figure 4. 1:36-scale model of Dam No. 2, Arkansas River

Characteristic	Dimension[1]	Scale Relations Model:Prototype
Length	L_r	1:36
Area	$A_r = L_r^2$	1:1,296
Velocity	$V_r = L_r^{1/2}$	1:6
Discharge	$Q_r = L_r^{5/2}$	1:7,776
Volume	$V_r = L_r^3$	1:46,656
Weight	$W_r = L_r^3$	1:46,656
Time	$T_r = L_r^{1/2}$	1:6

[1]Dimensions are in terms of length.

Model measurements of discharge, water-surface elevations, and velocities can be transferred quantitatively to prototype equivalents by means of the scale relations. Experimental data also indicate that the model-to-prototype scale ratio is valid for scaling stone in the sizes used in this investigation.

3 Tests and Results

Initial Tests

The flow condition used for design of the scour protection was one gate fully open to the normal upper pool (el 162) and a tailwater 6 ft lower than the minimum existing tailwater, el 119. The design was also tested with pool elevations higher than normal to observe its performance. These flow conditions were considered representative of those that might occur as a result of ice and debris passage, equipment malfunction that might cause the gate to remain open, vandalism, or a navigation accident. The tests were performed for 8 hr prototype time because it was felt that the flow conditions caused by one of the scenarios mentioned could be corrected within this time period. The riprap was considered unstable if movement along the blanket was observed. Movement of riprap at the toe of the protection was not considered failure if it was caused by scour of the exit channel. This movement at the toe does however indicate the need for adequate toe protection for the prototype.

Initial tests were conducted to determine the stability of the riprap, designated Riprap No. 7 by the US Army Engineer District, Little Rock, used to repair portions of the area downstream from the stilling basin after the navigation accident. The gradation of Riprap No. 7 used in the model is shown in Plate 2. The riprap blanket was 13.5 ft thick and consisted of a mixture of graded stones ranging in size from 1.5 to 4.5 ft (equivalent diameter). The weight of the stones for riprap with a specific weight of 165 pcf can be determined from

$$W_{lb} = 0.05(d_{in})^3 \tag{1}$$

where

W = weight of stone, lb
d = equivalent diameter of stone, in.

The riprap sloped downward from the stilling basin end sill on a 1V on 7H slope for approximately 90 ft downstream as shown in Plate 3. This

placement of Riprap No. 7 was determined from drawings of the repair job furnished by the Little Rock District. Also, Riprap No. 5 was placed upstream from the face of the dam for 90 ft to observe its stability during initial testing. The gradation of Riprap No. 5 is shown in Plate 4.

One gate half open

Tests 1-5 were conducted with gate 8 opened 14 ft and the pool and tailwater conditions shown in Table 1. A 14-ft gate opening was considered to be representative of a gate opened half-way. The tests were conducted by setting the appropriate discharge with a high tailwater, lowering the tailwater to the desired elevation, running this condition for a specified time period, turning off the discharge, and draining the model slowly so the riprap and scour pattern would not be disturbed to observe if riprap displacement had occurred. Riprap No. 7 downstream from the stilling basin was found to be unstable with pool el 162 and tailwater el 135 (Test 5, Table 1). The tests indicated that gate openings of 14 ft and greater should not be allowed with the tailwater lower than el 140. Results from Test 5 (Table 1) are shown in Photo 1.

One gate fully open

Tests were conducted to determine the stability of Riprap No. 7 downstream from the stilling basin for flow conditions caused by normal upper pool (el 162), one gate fully open, and various tailwater elevations. The riprap was found to be unstable for tailwater elevations below 150. Results from Test 8 (Table 1) are shown in Photo 2.

Riprap No. 7 was then tested under abnormal conditions. The first of these tests (Test 9, Table 1) reproduced pool (el 170) and tailwater (el 147.5) elevations that existed during the December 1982 barge accident. The riprap failure for this condition was severe, as shown in Photo 3. The test was conducted with gate 10 fully open for a duration of 4 hr 30 min prototype time (45 min model time).

Previous tests had shown that Riprap No. 7 would fail with one gate fully open, normal pool, and tailwater elevations lower than 150. Engineer Technical Letter 1110-2- 290[1] suggests that new project stilling basin design conditions include one gate fully open with normal headwater and minimum tailwater (gate misoperation). This type flow condition was observed to determine the adequacy of the existing stilling basin and the effects of this type flow on the Riprap No. 7 (Test 16, Table 1). The riprap was tested with the normal pool elevation, an extremely low tailwater elevation of 122 (3 ft

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[1] Office, Chief of Engineers, US Army. 1983 (31 Oct). "Low Head Navigation Dam Stilling Basin Design," ETL 1110-2-290, US Government Printing Office, Washington, DC.

higher than the basin apron), and one gate open fully for 8 prototype hours (1 hr 20 min model time). The flow swept completely out of the stilling basin, and a hydraulic jump formed over the riprap protection. The results from this test are shown in Photo 4.

Alternate Protection Designs

Type 2 scour protection design

The type 2 scour protection design was tested to determine the stability of larger riprap. The type 2 design consisted of 4.5- to 6-ft-diam rocks placed 9 ft thick over a 4.5-ft-thick layer of the existing riprap. Photo 5 shows the type 2 design in place below one gate bay. Tests indicated the type 2 design was unstable with one gate half open for tailwater elevations less than 135 (Table 1, Tests 12 and 13) and with one gate open fully, and tailwater elevations less than 140 (Table 1, Tests 14 and 15). These tests were conducted for 8 prototype hours with a normal pool elevation.

Type 3 scour protection design

Since failure of the type 2 scour protection occurred with tailwater elevations much higher than the minimum tailwater anticipated at the project, structural modifications were made downstream from the existing stilling basin. The type 3 design shown in Photo 6 consisted of barges, 175 ft long by 26 ft wide by 12 feet deep, filled with grouted rock and placed downstream from the existing stilling basin. This design was tested in an attempt to provide a secondary stilling basin. The basin extended 220 ft downstream as shown in Plate 5 and contained a 6-ft-thick blanket of Riprap No. 7 offset 4.5 ft below the top of the barge for a distance of 125 ft downstream from the end of the barges. The type 3 scour protection design remained stable when tested for 8 hr with one gate fully open, normal upper pool elevation, and tailwater el 118.

Type 4 scour protection design

Because the constructibility of the type 3 design was questionable, the type 4 scour protection design, shown in Photo 7, was tested next. This design was considered more feasible, and details of the plan are shown in Plate 5. The design consisted of the same size barges used in the type 3 design placed on a 1V on 6H downward slope beginning immediately downstream from the end of the existing basin at el 119 and terminating at el 90. A 6-ft-thick layer of Riprap No. 7 was placed horizontally for 182 ft downstream. The type 4 scour protection design remained stable when tested for 8 hr with gate 6 fully open, normal upper pool, and tailwater el 118. Flow conditions during the test are shown in Photo 8. Supercritical flow exited the original basin, and a hydraulic jump formed in the secondary stilling basin. Adequate energy dissipation occurred in the secondary stilling basin, and scour in the exit channel

was minimal. Riprap No. 5 placed upstream from the structure remained stable for all conditions observed.

The tailwater elevation with which tests should be performed was a matter of uncertainty. El 113 was chosen as the minimum expected tailwater that might occur at the project. This was based upon an additional 6 ft of scour in the exit channel relative to the existing minimum tailwater (el 119). Tests conducted with any one of gates 4-13 opened fully to the normal pool, el 162, and a tailwater el of 113 indicated the type 4 scour protection design was stable. The type 4 scour protection design also remained stable for the various conditions shown in Table 1 for Tests 20-23.

Type 5 scour protection design

A test was requested by Little Rock District with additional larger riprap placed on top of Riprap No. 7, which had been tested previously and found to be unstable with one gate fully opened and tailwater elevations below 150. This plan, designated the type 5 scour protection design, shown in Photo 9, consisted of 4- to 6-ft-diam stones placed on top of the existing Riprap No. 7 beginning approximately 30 ft downstream from the end sill and terminating approximately 90 ft downstream from the end sill. The plan was tested using gate bay 4, and was found to be unstable for tailwater elevations equal to or less than 135 with the normal upper pool and gate 4 open fully.

Type 6 scour protection design

The type 6 scour protection design shown in Photo 10a was a secondary stilling basin located immediately downstream from the existing basin. Details of the basin are shown in Plate 6. The basin design was based on guidance provided in EM 1110-2-1605.[1] Flow conditions with normal upper pool, gate 6 fully open, and tailwater el 113 are shown in Photo 10b. A forced hydraulic jump occurred in the secondary basin, but Riprap No. 7 placed downstream from the basin was stable and scour in the exit channel was minimal. This basin was originally designed to function with upper pool el 170 and tailwater el 132. These are the conditions that would have existed during the barge accident if the tailwater was at its minimum elevation for the discharges that occurred. The basin performed adequately for these conditions. The conditions stated previously, normal upper pool el 162, one gate fully open, and tailwater el 113, were considered more severe and the basin also functioned satisfactorily for these conditions.

[1] Office, Chief of Engineers, US Army. 1987 (12 May). "Hydraulic Design of Navigation Dams," EM 1110-2-1605, US Government Printing Office, Washington, DC.

Type 7 scour protection design

Tests were conducted with the barges of the type 4 scour protection plan raised 4 ft. Little Rock District requested these tests because the barge placement proposed in the type 4 scour protection plan encroached upon an existing clay blanket beneath the existing riprap downstream of some gate bays. This plan was designated the type 7 scour protection design, shown in Plate 7. The plan remained stable after 8 hr (prototype) with normal pool and tailwater el 112.9 (Test 26, Table 1). Supercritical flow swept across the barges, and the toe of the jump formed near the downstream end of the barges as shown in Photo 11. Considerable turbulence was observed in the flow passing over the riprap protection, but no displacement was observed.

Type 8 scour protection design

The barges previously tested were increased in size from 175 by 25 by 12 ft to 190 by 35 by 12 ft since this size is more common in the Little Rock area. Riprap No. 7 was placed at el 87 for a distance of 182 ft downstream from the barges to form the type 8 scour protection plan, shown in Plate 7. A test conducted for 8 hr (prototype) with gate 13 opened fully to the normal upper pool and tailwater el 113 revealed scour in the exit channel was minimal and the riprap protection was stable.

Tests were then conducted to determine the minimum length of Riprap No. 7 needed downstream of the barges. Each of these tests was conducted for 8 hr (prototype) with gate 13 opened fully to the normal upper pool and a tailwater el 113. The results shown in Photo 12 indicated scour downstream from the riprap protection was not excessive for any of the blanket lengths tested. Riprap protection downstream from the barges is essential to prevent local scour and undermining of the end of the barges. The scour observed in the model is only a relative indication; however, the potential exists for greater scour to occur in the prototype.

Type 9 scour protection design

To provide protection for the area immediately downstream from the barges, Riprap No. 7 was placed at el 87 for a length of 50 ft, followed by a 50-ft-long blanket of Riprap No. 8. Riprap No. 8 consisted of a 36-in.-thick blanket of stone with a D_{50} size of 16 in. and the gradation shown in Plate 8. The purpose of placing the smaller Riprap No. 8 was to reduce the local turbulence above the stone protection downstream of Riprap No. 7 and to transition a less turbulent flow condition on the natural channel bottom. These modifications were designated the type 9 scour protection design. This design was tested with gate 13 opened fully to the normal upper pool and tailwater el 113 for 8 hr (prototype). The results shown in Photo 13 revealed that the riprap was stable and scour was minimal.

Previous tests with the type 9 scour protection design had been conducted downstream from a middle gate. Additional tests were necessary to evaluate the stability of the design placed downstream from the end gates. The barge revetment and riprap protection were placed across the entire structure as shown in Plate 9. The results after 8 hr (prototype) operation with gate 16 opened fully to the normal upper pool and tailwater el 113 are shown in Photo 14. Riprap No. 7 and 8 were displaced and considerable scour was evident along the toe of the channel side slopes (which at the time these tests were conducted were molded of a nonerodible material). The results of a similar test with gate 1 for 4 hr (prototype) are shown in Photo 15. Riprap No. 7 and 8 were displaced downstream from the barges, but due to the topography of the exit channel in this area, scour did not occur along the channel side slopes. An eddy formed and prevented flow concentration along the left bank.

The length of Riprap No. 7 provided along the channel bottom immediately downstream from the barges was increased from 50 ft to 100 ft downstream of gates 15 and 16 and the length of Riprap No. 8 was maintained at 50 ft. Tests were conducted individually for 8 hr (prototype) with gates 1 and 16 opened fully to the normal upper pool and tailwater el 113. The riprap on the channel bottom downstream of the barges remained stable. Because the side slopes were still molded in a nonerodible material, additional testing was required to investigate the stability of Riprap No. 7 placed on the side slopes.

Side Slope Protection

Side slope riprap on left bank

Initially, Riprap No. 7 was placed for a distance of 280.8 ft downstream from the end of the training wall (training wall at sta 2+21) along the left channel side slope. Riprap No. 7 was also placed on the channel bottom downstream from the barge revetment below gates 1 and 2 for a distance of 100 ft followed by Riprap No. 8 for 50 ft. A test was conducted with gate 1 opened fully to the normal upper pool and a gradual lowering of the tailwater in an attempt to reach el 113. When the tailwater reached el 130, some of the stones on the side slopes were displaced rapidly; therefore, this condition was tested for a duration of 1 hr (prototype) to observe the movement of the riprap. A significant amount of riprap had been displaced and the filter underneath the riprap was exposed in two locations. The filter was exposed about 85 ft downstream from the training wall midway up the side slope and also approximately 280 ft downstream from the training wall as shown in Photo 16. The riprap displacement, which was approximately 280 ft downstream from the training wall, occurred where the riprap transitioned back to the nonerodible material and was not considered representative of actual conditions.

Additional Riprap No. 7 was placed 50 ft downstream from the structural wall to act as a sacrificial dike as shown in Photo 17. Riprap No. 7 was

extended an additional 320 ft farther downstream on the left bank, providing side slope protection 600 ft downstream from the end of the training wall. This was done to move the disturbance caused by the transition from the Riprap 7 to the nonerodible material on the side slope farther downstream. A test was conducted for 8 hr (prototype) with gate 1 opened fully to the normal upper pool and tailwater el 130. Riprap was displaced in several areas and the filter was exposed about 94 ft downstream from the training wall as shown in Photo 17. The toe of the left side slope was undermined for the entire length causing riprap on the side slope to fail.

Side slope toe protection

The sacrificial dike was extended to 120 ft downstream and an additional 25-ft-wide section of Riprap No. 7 was placed from the toe of the side slope out into the channel along the entire length of riprapped side slope. A test was conducted for 8 hr (prototype) with gate 1 opened fully to the normal upper pool and tailwater el 130. The outside edge of the additional 25 ft of riprap placed along the toe of the side slope was undermined causing movement of the riprap on the side slope. Riprap in the vicinity of the sacrificial dike moved, but the filter was not exposed. The width of Riprap No. 7 along the toe of the side slope was increased from 25 to 75 ft, and another test was conducted for 8 hr with gate 1 opened fully to the normal upper pool and tailwater el 130. The scour along the toe was not excessive, and the riprap on the side slope did not fail.

A test was then conducted for 8 hr (prototype) with gate 1 opened fully to the normal upper pool and tailwater el 113 to determine the stability of Riprap No. 7 on the side slope for this flow condition. Some of the riprap in the sacrificial dike (approximately 40-60 ft downstream from the training wall) was displaced, but overall, the riprap held favorably. The riprap was considered adequate protection if a flow condition of this nature could be brought under control and improved in an 8-hr period.

Side slope riprap on right bank

Tests were conducted to determine the stability of the riprap on the slope on the right side of the exit channel. Riprap was placed for a distance of 585 ft downstream from the training wall and a 75-ft-wide blanket of Riprap No. 7 was placed at the toe along this length. A 120-ft-long sacrificial dike was also installed. A test was conducted for 8 hr (prototype) with gate 16 opened fully to the normal upper pool and tailwater el 130. Movement was observed about 97 ft downstream from the training wall, but adequate protection was provided. A test was then conducted for 8 hr with gate 16 opened fully to the normal upper pool and tailwater el 113. Again, some of the riprap forming the sacrificial dike was displaced, but this was the purpose of the dike. Overall, the riprap provided adequate protection.

Constructibility Tests

A series of tests were conducted to determine the stability of the barge revetment and riprap protection with the downstream ends of the barges, or group of barges, placed unevenly across the area below the structure. The downstream ends of the barges were staggered 6 ft above and 6 ft below their positions in the type 9 scour protection plan to represent nonuniform placement, as shown in Plate 10. A test was conducted for 8 hr (prototype) with gate 11 opened fully to the normal upper pool and tailwater el 113. A group of raised barges adjoined a group of lowered barges downstream from the center of gate 11. Scour was no worse than had been observed previously, and the riprap remained stable. A test was then conducted for the same conditions with gate 1 fully open. The downstream end of the barge closest to gate bay 1 was lowered for this test. Some riprap in the dike was displaced, and some of Riprap No. 8 downstream from gate bay 3 was displaced; but this was considered acceptable.

A test was then conducted downstream from gate 10 where the barges were 6 ft higher than their original placement. Riprap No. 8 downstream from the barges failed during this test due to the flow conditions that occurred with gate 10 opened fully to the normal upper pool and tailwater el 135. The entire 50-ft blanket was washed away as shown in Photo 18. An additional 50 ft of Riprap No. 7 (total length of 100 ft) followed by 50 ft of Riprap No. 8 was placed downstream from gate 10 and the test repeated. Again, the Riprap No. 8 was washed downstream. Riprap No. 8 was replaced with Riprap No. 9 (d_{50} = 24 in.). The gradation of this riprap is shown in Plate 11. A test was conducted for 8 hr (prototype) with gate 10 opened fully to the normal upper pool and tailwater el 135. Riprap No. 9 washed downstream as shown in Photo 19. Test results indicated that a significant amount of additional riprap will be required if the downstream ends of the barges are placed much higher than el 91.5. Since the Riprap No. 9 failed with the tailwater at el 135, tests were not conducted with lower tailwater.

Another test was conducted downstream from gate 7 where the barges were 6 ft lower than their original placement. Riprap No. 8 downstream from these barges was stable when tested with gate 7 opened fully to the normal pool and tailwater el 135. Displacement at the toe of the protection shown in Photo 20 could be prevented with additional riprap placed in this area; therefore, this movement was acceptable. Additional tests with lower tailwater were not conducted since previous tests indicated the riprap downstream from a group of raised barges was not stable at a tailwater el of 135.

Apparently, the group of raised barges caused the flow to attack the area downstream from these barges more severely than if the barges were lowered. An additional thickness of Riprap No. 7 was required at the downstream ends of the barges that had been raised 6 ft to prevent loss of material beneath the raised barges. The lateral transition of the riprap downstream from a barge raised 6 ft to a barge lowered 6 ft is not desirable due to the formation of

unsymmetrical flow conditions. Uniform placement of the barges will help prevent these types of flow conditions from developing.

Tests were requested by the Little Rock District to determine the stability of the scour protection in case a barge was not placed properly and the upstream end of the barge became lodged on the end sill. A test was initiated with a barge between gates 15 and 16 placed on the end sill. The test was conducted for 2 hr (prototype) with gate 16 opened fully to the normal upper pool and tailwater el 113. Severe riprap displacement occurred along the side slope as shown in Photo 21. The raised barge concentrated flow downstream from gate 16 and prevented it from spreading out. This caused direct attack on the side slope riprap. Another test was conducted depicting this type placement behind gate bay 7. The same test conditions were observed, but for 8 hr (prototype), and no riprap failure occurred. The end of the barge acted as a baffle deflecting the jet upward and downstream, and the spray falling back to the water surface was not strong and concentrated. Therefore, riprap failure did not occur. The flow conditions caused by the raised barge are undesirable, and much emphasis should be placed on constructing the barge revetment as uniformly as possible.

Additional tests were conducted to determine discharges and operation schedules that will provide safe working conditions during the placement of the scour protection materials. Various tests were performed to observe flow conditions with different gate setting and discharges. The test conditions are shown in Table 2. The tests were conducted with conditions that would occur if barges were being placed behind gates 2, 4, or 8. This was considered representative of all situations that could occur during placement. Conditions during placement behind gates 15 and 13 would be the same as placement behind gates 2 and 4. Test results indicated that when the end gate is used when working behind gates 4 or 13, it should not be raised higher than 1 ft and should not be open more than the gate adjacent to it.

Photo 22 shows flow conditions downstream from gate 4 with a discharge of 50,000 cfs and pool el 162 when gates 2-6 are closed. This condition would exist when barges are being placed in the vicinity of gate 4. No adverse flows were observed and velocities were less than 3.5 fps on the surface. Flow circulation occurred in the working area but was considered slight.

Photo 23 shows flow conditions with gates 1-4 closed for a discharge of 50,000 cfs and pool el 162. These conditions would exist when barges are being placed in the vicinity of gate 2. No adverse flow conditions were observed, flow circulation was minimal, and velocities were less than 3.5 fps. Photos 24 and 25 show flow conditions for a discharge of 15,000 cfs with gates 2-6 and 1-4 closed, respectively. A larger flow circulation pattern was observed with the higher tailwater, but no harmful conditions were observed.

Model tests were recommended by the Little Rock District to determine the smaller of the following discharges: either the discharge at which harmful flow conditions would occur downstream from the five gates that would be

closed for placement of the scour protection plan or the discharge that would cause failure of the existing Riprap No. 6 if it were downstream from an operating gate where new scour protection is not in place. Riprap No. 6 along with Riprap No. 7 was used to repair portions of the damaged areas after the navigation accident. It consisted of graded riprap with a D_{50} (min) of 19 in. and a blanket thickness of 6 ft. If hydrological forecasts indicate that this discharge might occur during construction, and an area has been prepared for placement of barges, then the contractor would be directed to riprap this area so all gates could be used to pass this flow. Tests indicated that with up to a discharge of 112,600 cfs, pool el 164, and tailwater el 150, the riprap and sand test sections remained stable. These flow conditions are shown in Photo 26. Discharges higher than this caused the model sand bed behind gates 6-10 to begin to scour, which was considered an adverse condition. The Little Rock District chose to let the pool rise 2 ft higher than normal to pass these increased discharges.

4 Discussion of Results and Conclusions

Model tests to determine scour protection for Dam No. 2, Arkansas River, indicated that loose, graded riprap would not provide the protection required for the design flow condition. The flow condition used for design of the scour protection was one gate fully open to the normal upper pool and a tailwater 6 ft lower than the minimum existing tailwater. The design was also tested with pool elevations higher than normal to observe its performance. These flow conditions were considered representative of those that might occur as a result of ice and debris passage, equipment malfunction that causes the gate to remain open, vandalism, or a navigation accident. The tests were performed for 8 hr prototype time because it was felt that the flow conditions caused by one of the scenarios mentioned could be corrected within this time period.

The best design that would prevent scour caused by the flow conditions with single gate operations and minimum tailwater is a secondary stilling basin with baffle blocks and an end sill. It is an effective energy dissipator for the supercritical flow that exits the existing stilling basin. Performance of this type structure was observed with the type 6 scour protection design. Since this project could not be dewatered to construct the secondary stilling basin, based on an economical analysis, this method was not feasible.

The type 9 scour protection design shown in Plate 9 provided adequate protection for single gate operations with minimum tailwater. The design consisted of a 15-ft length of riprap to be placed at the same elevation as the existing end sill and then grouted to form a large mass. Following the grouted riprap were barges 190 ft long by 35 ft wide by 12 ft deep placed on a 1V on 6H downward slope. The barges were filled with riprap and also grouted to form a large and solid mass. The large mass of revetment was necessary to withstand the forces caused by the hydraulic jump. A 50-ft length of Riprap No. 7 offset 4.5 ft below the top of the downstream end of the barge was placed downstream from the barge, followed by a 50-ft length of Riprap No. 8. This smaller size riprap helped to reduce the severity of the localized disturbances at the end of the blanket of Riprap No. 7 and transition the flow to the natural river bottom.

Tests revealed that if a barge was placed on a slope milder than 1V on 6H and the downstream end of the barge was higher than desired, excessive lengths of Riprap No. 7 were required downstream from the barge. Efforts should be made to keep the downstream end of the barge from projecting above el 91.5. Adverse flow conditions can result if there is more than a 6-ft vertical offset from one barge to the one adjacent to it. Riprap No. 7 was required downstream from the barges due to the excessive velocities and turbulence that occur with single gate operations and minimum tailwater.

During tests with single gate operations, flow conditions were observed that could be damaging to the graded riprap downstream from the barges. These flow conditions occurred as the tailwater transitioned from the normal elevation to a lower elevation that caused supercritical flow to exit the existing basin. Supercritical flow exited the existing basin for normal upper pool and a single gate fully open with tailwater elevations lower than 140. An unstable, undular hydraulic jump occurred over the barges between tailwater el 140 and 125. This condition was observed for properly placed barges and misplaced barges. In this tailwater zone, much scour can occur in the exit channel along with displacement of the graded riprap if adequate toe protection is not provided. The damage is caused by the flow jet, which dives through the tailwater attacking the river bottom. When the tailwater is below 125, a stable hydraulic jump forms over the barges and the flow does not severely attack, the river bottom. This condition is emphasized here to point out the necessity of toe protection.

The scour potential of flow conditions caused by single gate operations with minimum tailwater was most severe downstream from gates 1 and 2 and 15 and 16. The flow leaving the existing basin from these gates was restricted by the training walls and side slopes of the end gates and could not spread out as it did when discharging from gates 3-14. Because concrete aprons extend downstream from gates 1 and 16 to the end of the training walls, barges are not required in these areas. Additional grouted riprap will be required on the channel invert behind gates 1 and 2 and 15 and 16 as shown in Plate 9. Additional amounts of Riprap No. 7 placed in the vicinity of the structural wall to form a sacrificial dike out for a length of 120 ft, as shown in Photo 17, will also be required due to the more severe flow conditions. A 75-ft-wide blanket of Riprap No. 7 should be placed on the channel invert at the toe of the side slope protection to prevent undermining of the side slope protection.

The structural wall located at the downstream end of the training walls is considered partly responsible for adverse flow conditions in its vicinity. The wall deflects flow upward similar to the actions of a flip bucket. When the flow plunges downstream, it causes excessive attack on the channel invert, the toe of the side slope, and the side slopes.

Riprap No. 5 placed upstream from the dam remained stable for all flow conditions observed. This indicates that the size of these stones is adequate to resist displacement from the turbulence generated from operations with a single gate fully open with normal and above-normal pool elevations. Obviously,

this graded riprap will be displaced by adverse currents that can occur from a sunken barge upstream from the dam as witnessed by the failure of the concrete scour slab during the barge accident of December 1982. The extent of protection required upstream from the dam is a judgment decision based on predicting the location of sunken barges resulting from a navigation accident. If a concrete apron extended far enough upstream, say twice the length of a barge or three times the width, chances are it would not have been undermined.

The scour protection design developed from the model study and shown in Plate 9 provides substantial scour protection for Dam No. 2, Arkansas River. Efforts should be made to maintain normal, equal-gate operations and thus reduce the potential for scour. Geotechnical considerations such as filters, uplift pressures, and seepage paths should be considered and incorporated into the design recommended from the model study.

Table 1
Test Conditions

Test No.	Design Type	Head Pool El	Tailwater El	Gate Opening ft	Gate No.	Remarks
1	Existing riprap	159.0	149.0	14	8	Stable
2		162.5	151.5	14	8	Stable
3		162.5	145.0	14	8	Stable
4		163.0	140.0	14	8	Stable
5		162.0	135.0	14	8	Unstable
6		161.5	150.0	Full	8	Stable
7		162.0	150.0	Full	8	Stable
8		162.0	145.0	Full	8	Unstable
9		170.0	147.5	Full	10	Severe riprap failure
10		162.0	135.0	5	5	Stable
11			130.0	5	5	Unstable
12	Type 2 design		135.0	14	10	Stable
13			130.0	14	10	Unstable
14			140.0	Full	10	Stable
15			135.0	Full	10	Unstable
16	Existing riprap		122.0	Full	3	Severe riprap failure
17	Type 3 design		117.5	Full	6	Stable
18	Type 4 design		118.0	Full	6	Stable
19	Type 4 scour protection design		114.3	Full	6	Stable
20			112.0	3	6	Stable
21			111.0	10	6	Stable
22		162.5	112.0	14	6	Stable
23		162.0	114.0	20	6	Stable
24	Type 5 design		135.0	Full	4	Failure
25	Type 6 scour protection design		114.8	Full	6	Stable
26	Type 7 scour protection design		112.9	Full	4	Stable
27	Type 6 scour protection design		112.0 - 155.0	14-20	6	No submerged jet, stable

Sheet 1 of 3

Table 1 (Continued)

Test No.	Design Type	Head Pool El	Tailwater El	Gate Opening ft	Gate No.	Remarks
28	Type 6 scour protection design	162.0	155.0 - 158.0	5	6	Depressed jet, stable
29	Type 8 scour protection design with 182 ft of Riprap No. 7 downstream of barges		113.3	Full	13	Stable
30	Type 8 with 130 ft of Riprap No. 7 downstream of barges		113.0		13	Stable
31	Type 8 with 100 ft of Riprap No. 7 downstream of barges				13	Stable
32	Type 8 with 70 ft of Riprap No. 7 downstream of barges				13	Stable
33	Type 8 with 50 ft of Riprap No. 7 downstream of barges				13	Stable
34	Type 8 with 25 ft of Riprap No. 7 downstream of barges				13	Stable
35	Type 9 scour protection design with 50 ft of Riprap No. 7 and 50 ft of Riprap No. 8 downstream of barges				13	Stable
36	Type 9 scour protection design with 50 ft of Riprap No. 7 and 50 ft of Riprap No. 8 downstream of barges				13	Stable

Sheet 2 of 3

Table 1 (Concluded)						
Test No.	**Design Type**	**Head Pool El**	**Tailwater El**	**Gate Opening ft**	**Gate No.**	**Remarks**
37	Type 9 scour protection design with 50 ft of Riprap No. 7 and 50 ft of Riprap No. 8 downstream of barges	162.0	113.0	Full	1	Failure
38	The same as Test 35 except 100 ft of Riprap No. 7 and 50 ft of Riprap No. 8 behind two gate bays on both sides. The remaining gates have 50 ft of Riprap No. 7 and 50 ft of Riprap No. 8.				16	Stable
39	The same as Test 35 except 100 ft of Riprap No. 7 and 50 ft of Riprap No. 8 behind two gate bays on both sides. The remaining gates have 50 ft of Riprap No. 7 and 50 ft of Riprap No. 8.				3	Stable
40	Riprap No. 7 on side slope (Same as Test 38)		130.0		1	Failure along side
41	Same as No. 38		150.0		16	Stable
42			140.0		16	Failure
43			145.0		16	Stable
Sheet 3 of 3						

Table 2
Safe Operating Conditions Determined from Constructibility Tests
Pool El 162

Tailwater El	Discharge, cfs	Gate No.	Working Barge Location Behind Gate Opening, ft															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
141.2	50,000	8	3.0	3.0	3.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	3.0	3.0	4.0
138.5		8	3.0	3.0	3.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	3.0	3.0	4.0
141.2		4	1.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	4.0
138.5		4	1.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	4.0
138.0		4	1.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.0	3.0	4.0	4.0	4.0	3.0	3.0	1.0
141.2		2	0.0	0.0	0.0	0.0	1.0	1.0	1.0	2.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0	4.0
138.5		2	0.0	0.0	0.0	0.0	1.0	1.0	1.0	2.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0	4.0
137.0		8	2.0	2.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	2.0	3.0
135.0		8	2.0	2.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	2.0	3.0
137.0	30,000	4	1.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	3.0
135.0		4	1.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	3.0
137.0		2	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	3.0
135.0		2	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	3.0
131.0	15,000	8	1.0	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	1.0	1.0
123.0		8	1.0	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	1.0	1.0
131.0		4	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.0	1.0	1.0
123.0		4	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.0	1.0	1.0
131.0		2	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.0	1.0
123.0		2	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.0	1.0

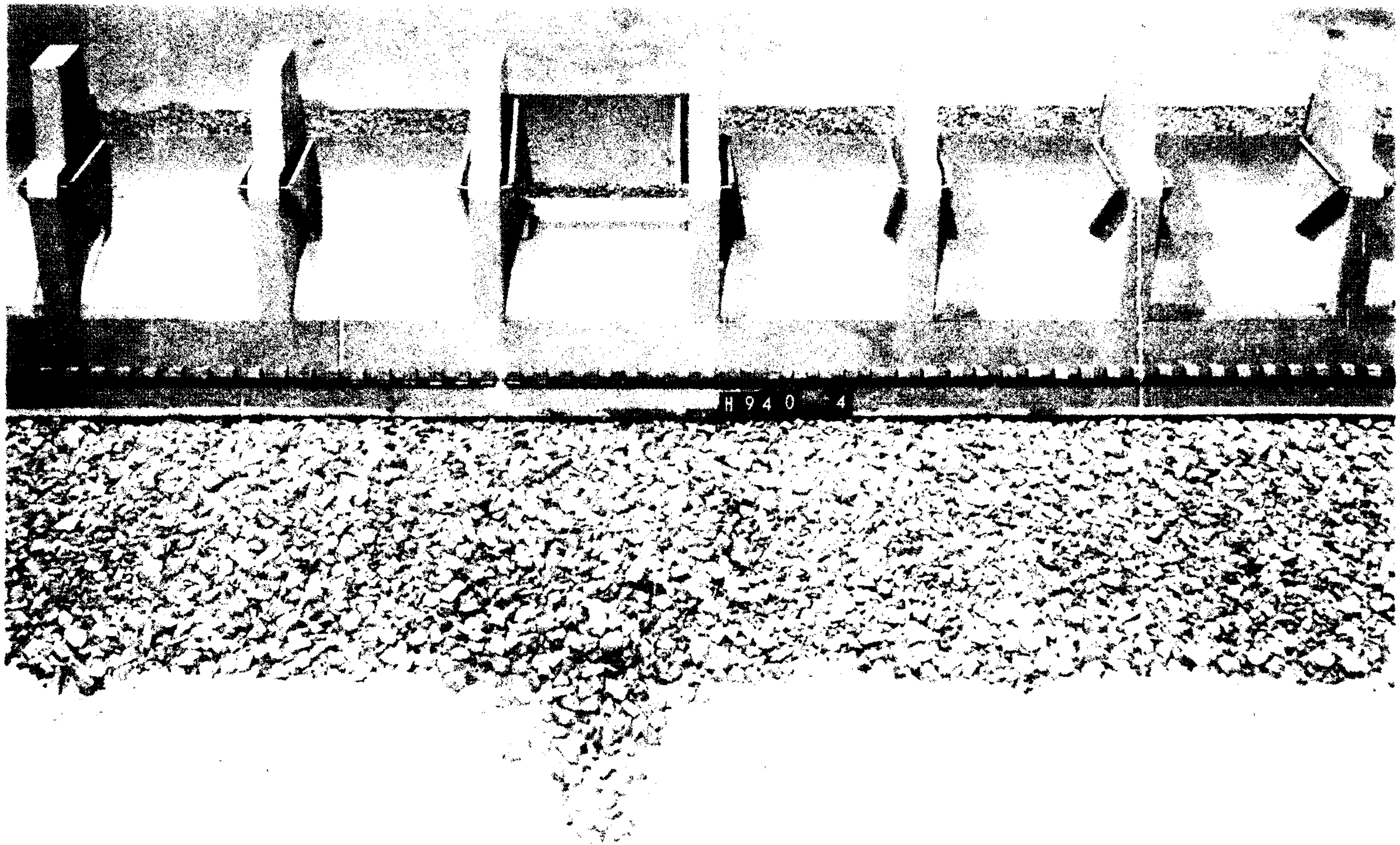


Photo 1. Failure of Riprap No. 7 and scour in the exit channel after 6 hr (prototype) of operation with gate 8 opened 14 ft, normal upper pool el 162, and tailwater el 135

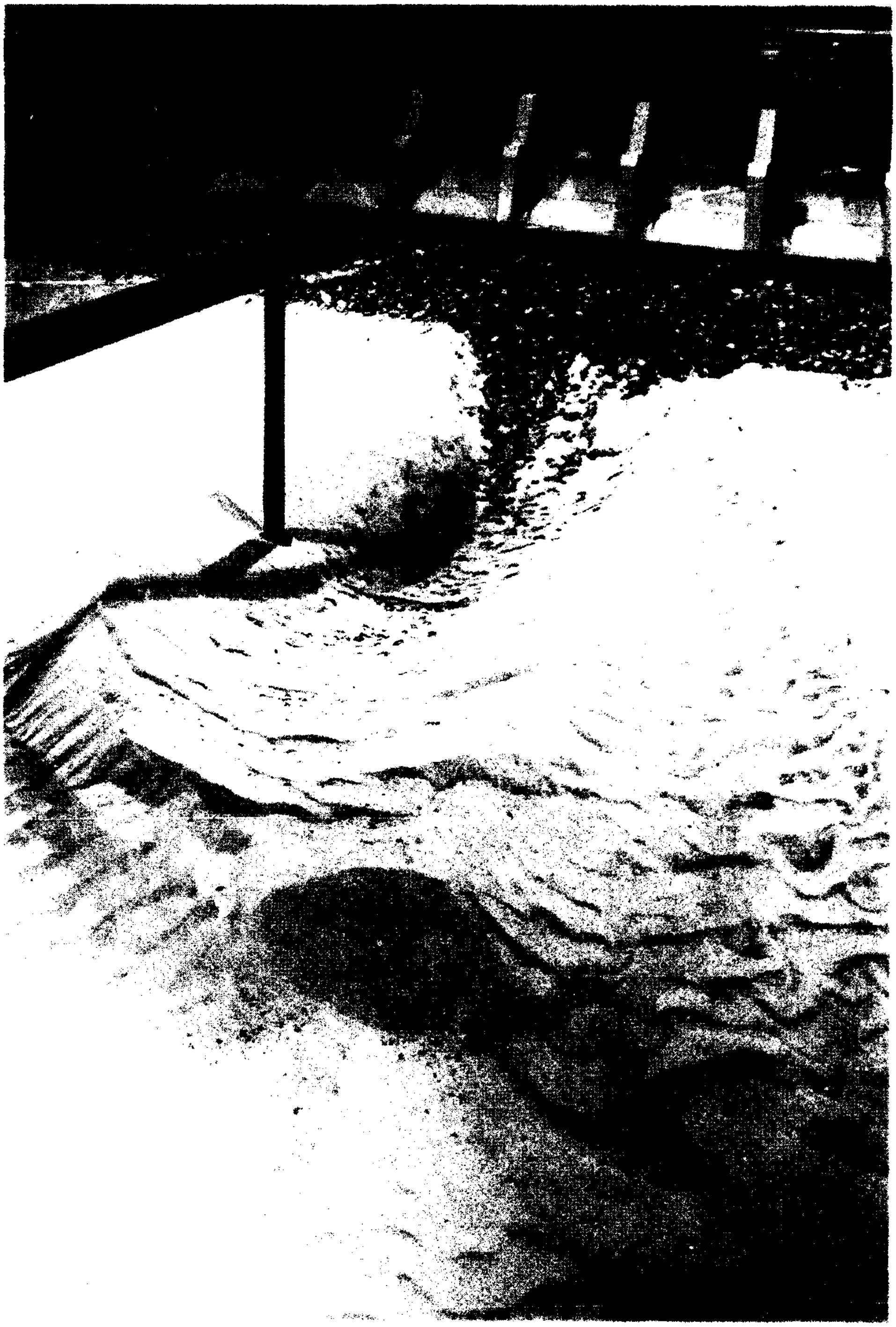
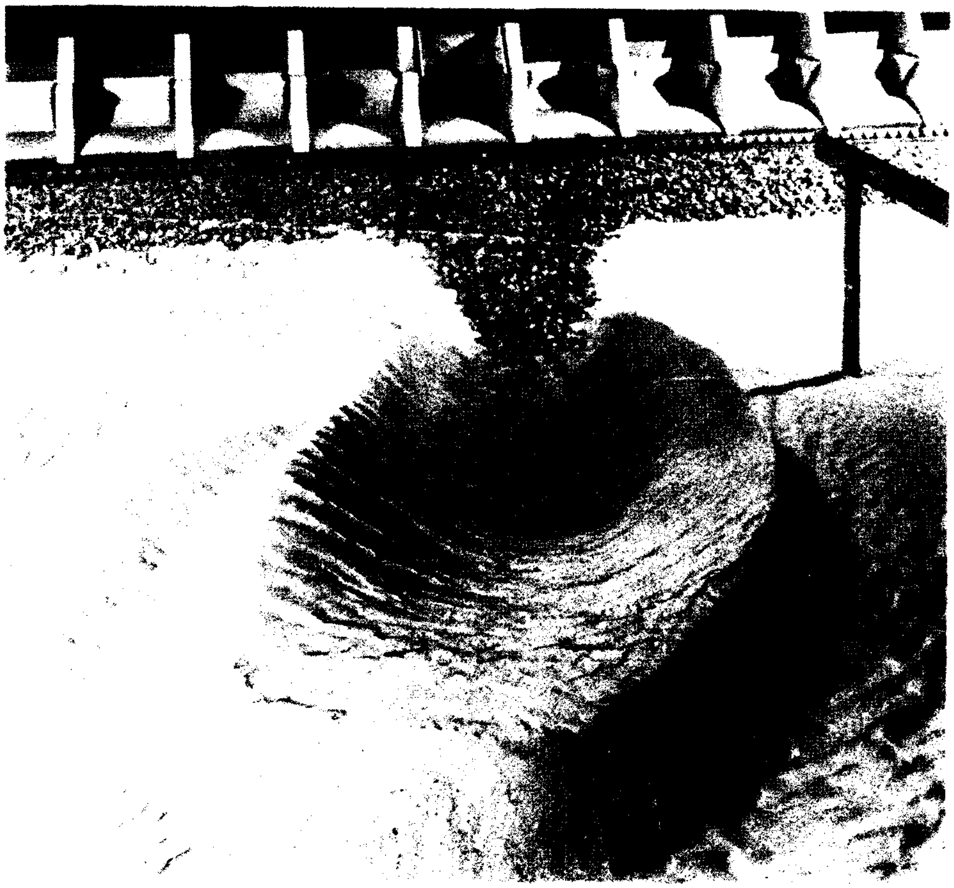


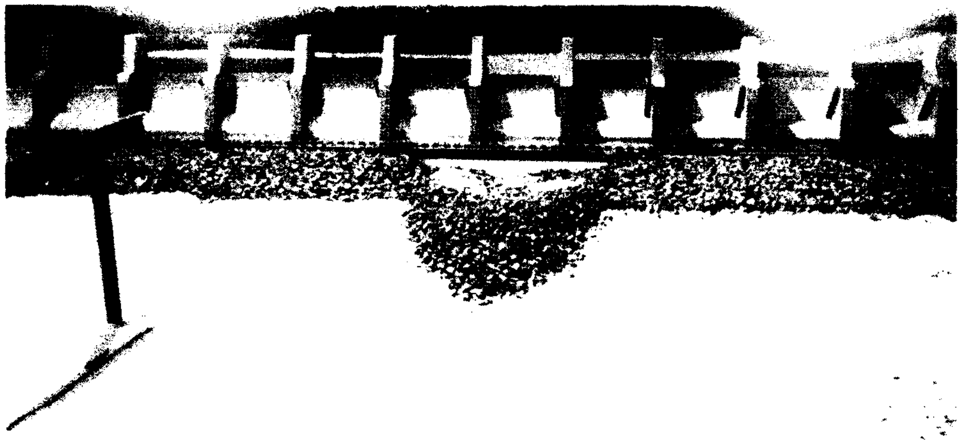
Photo 2. Failure of Riprap No. 7 and scour in the exit channel after 6 hr (prototype) of operation with gate 8 fully opened to the normal pool and tailwater el 145



a. Scour in exit channel

b. Riprap failure

Photo 3. Failure of Riprap No. 7 and scour in the exit channel after 4.5 hr (prototype) of operation with gate 10 fully opened, upper pool el 170, and tailwater el 147.5



a. Scour in exit channel

b. Riprap failure

Photo 4. Failure of Riprap No. 7 and scour in the exit channel after 8 hr (prototype) of operation with one gate fully open, normal upper pool elevation, and tailwater el 122

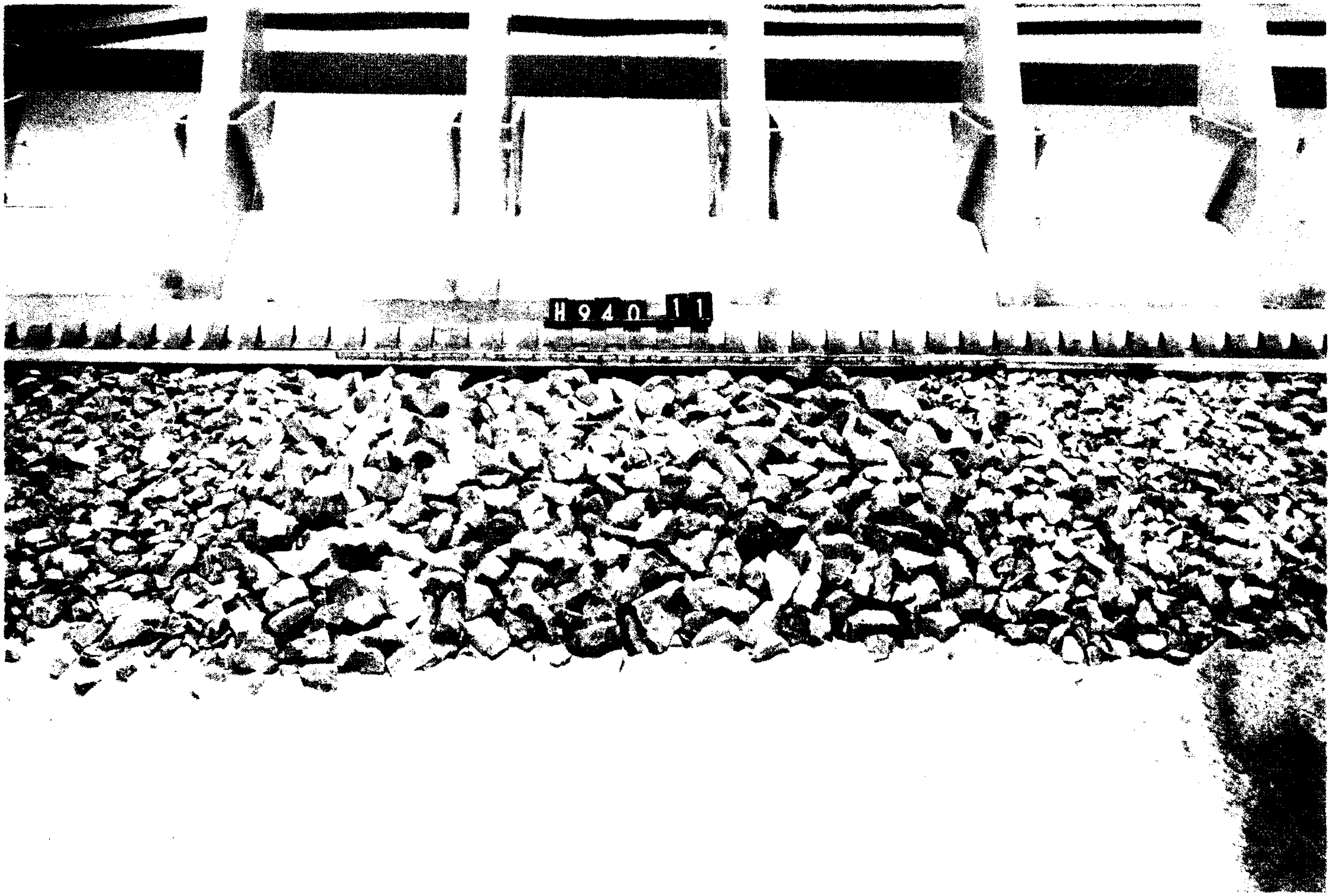


Photo 5. Type 2 scour protection design placed downstream of one gate bay

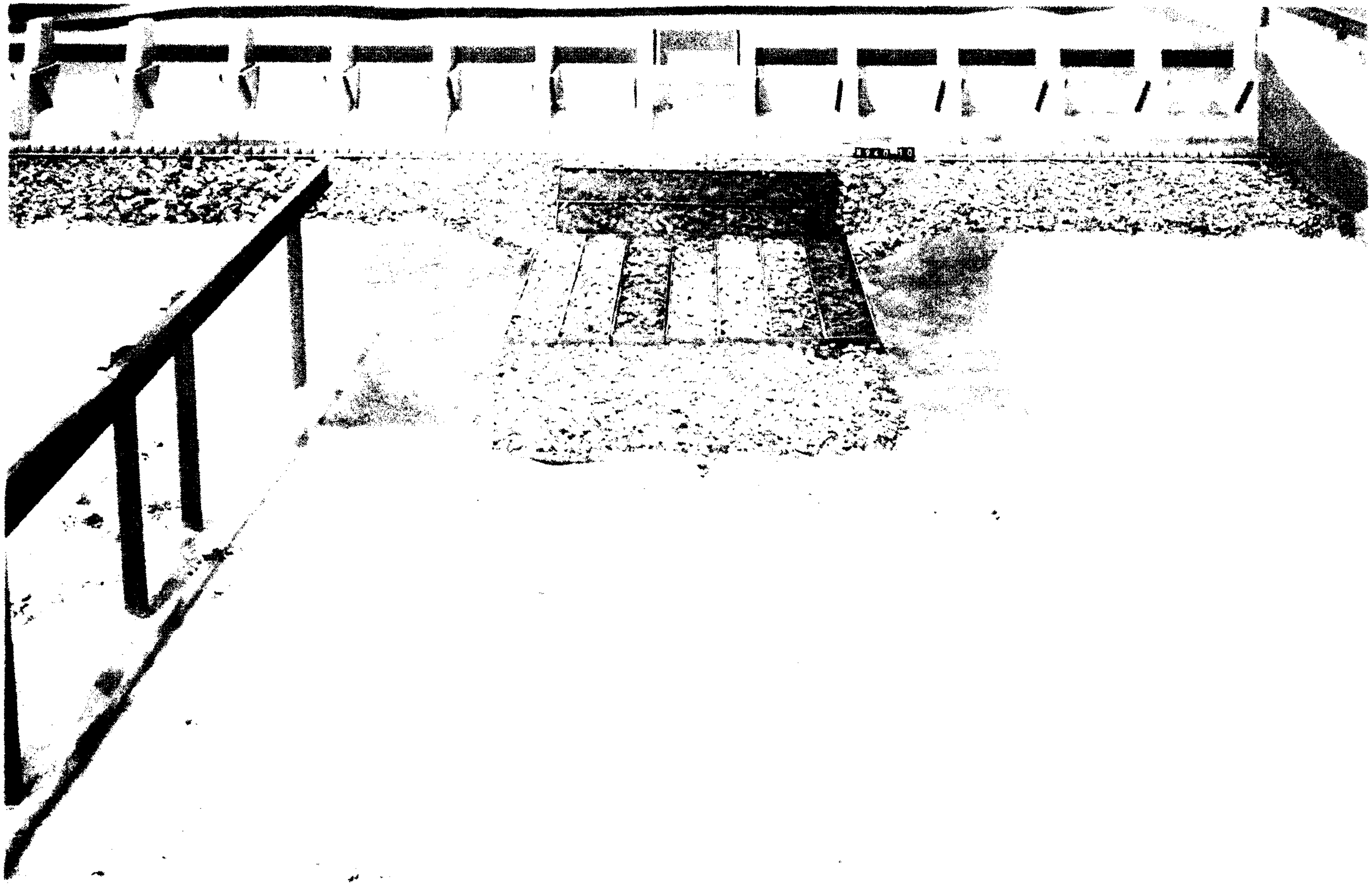
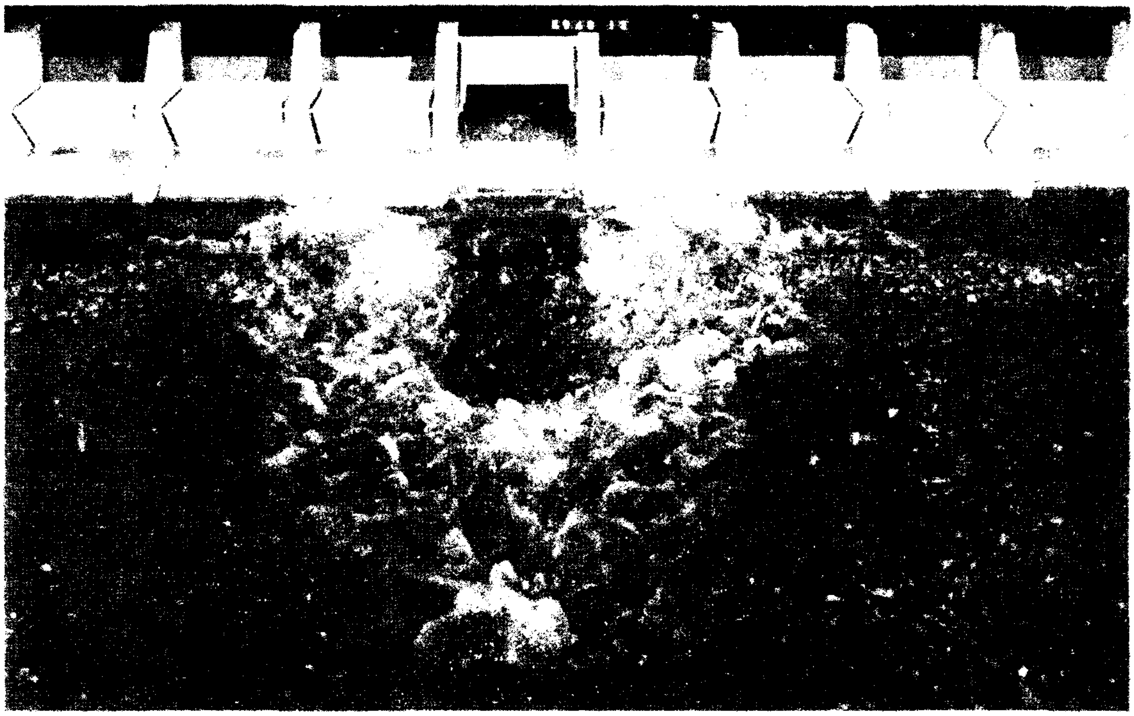
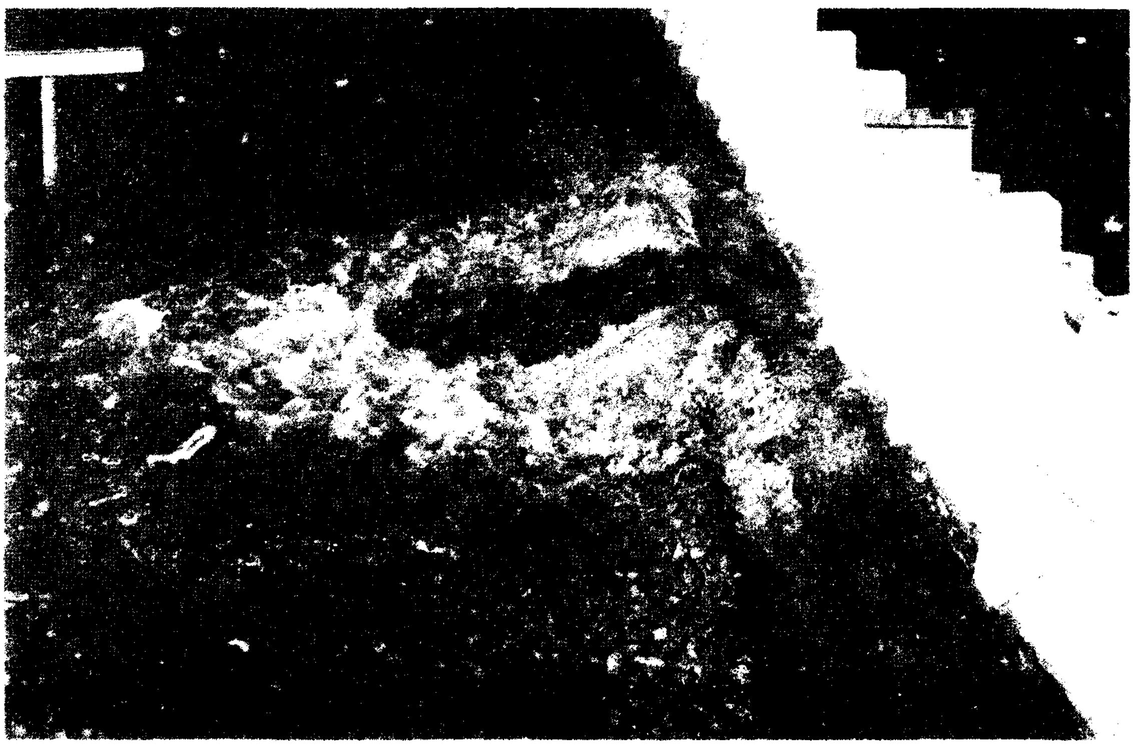


Photo 6. Type 3 scour protection design

Photo 7. Type 4 scour protection design



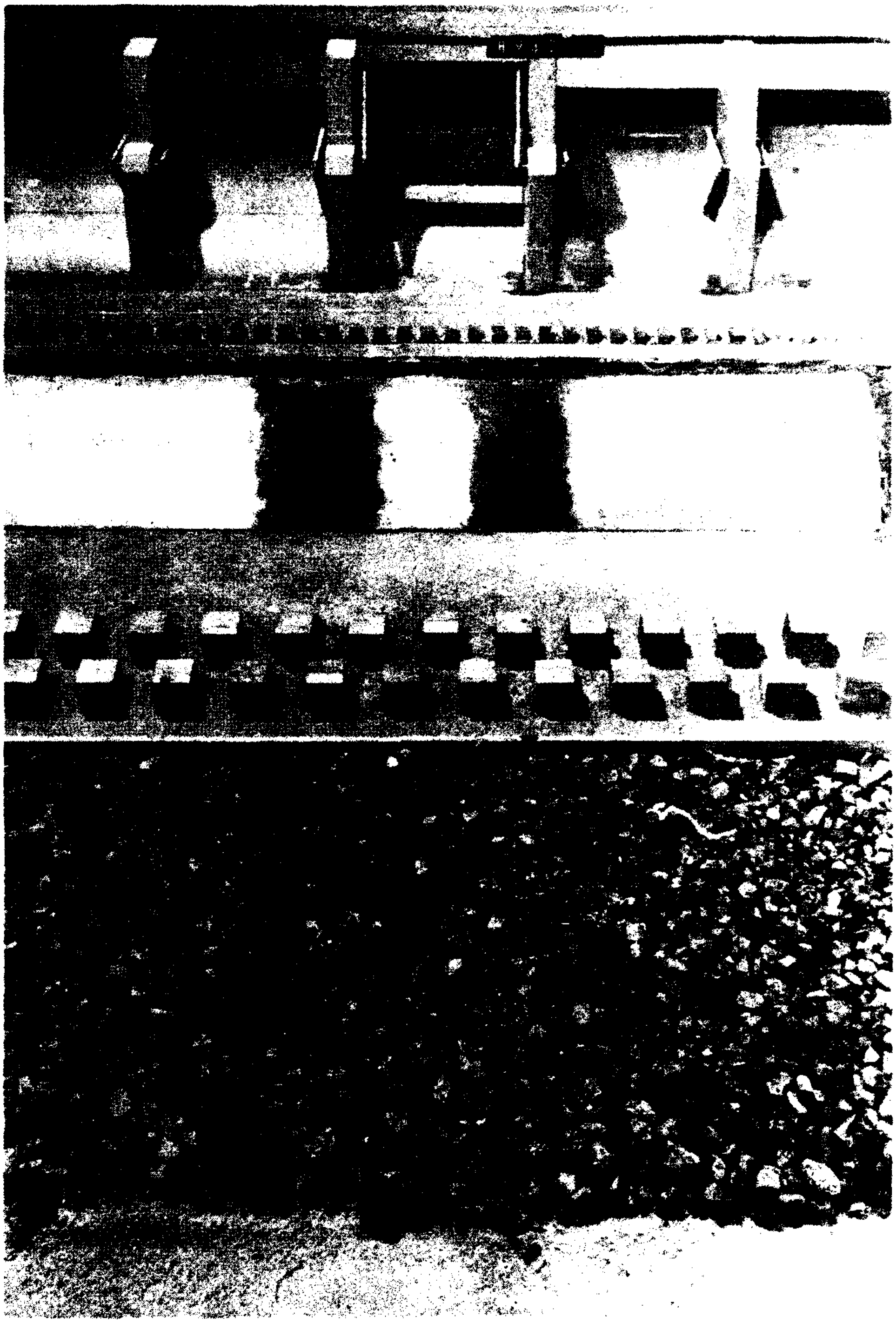
a. Looking upstream



b. Side view

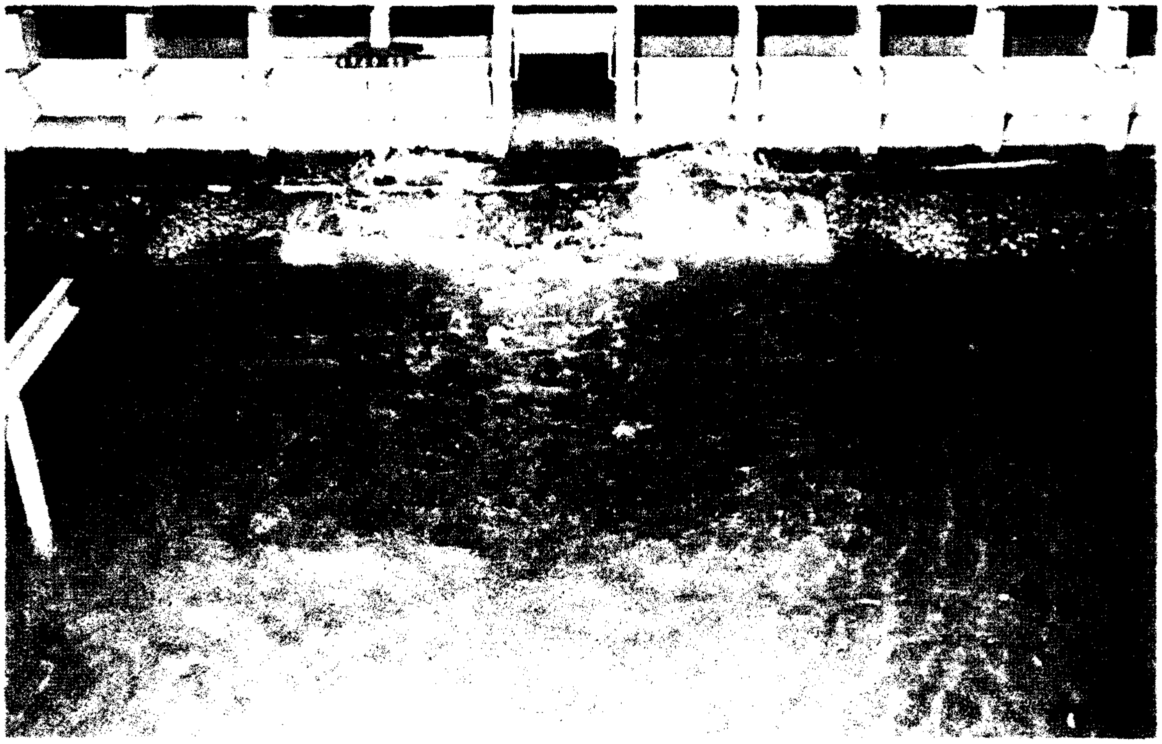
Photo 8. Flow conditions with type 4 scour protection design, normal upper pool, gate 6 fully open, tailwater el 118

Photo 9. Type 5 scour protection design



a. Dry bed view

Photo 10. Type 6 scour protection design (Continued)



b. Flow conditions with one gate fully open normal upper pool, tailwater el 113

Photo 10. (Concluded)

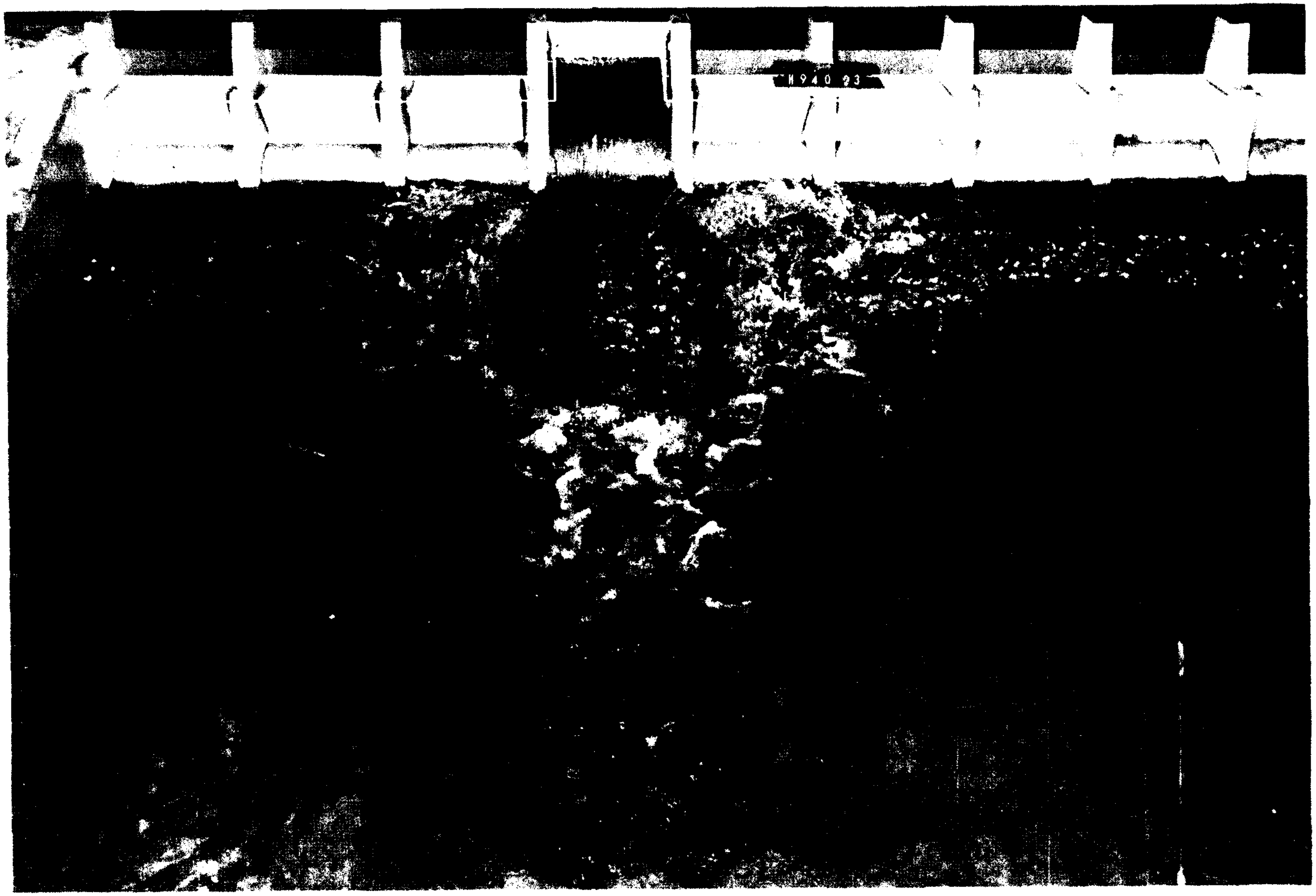
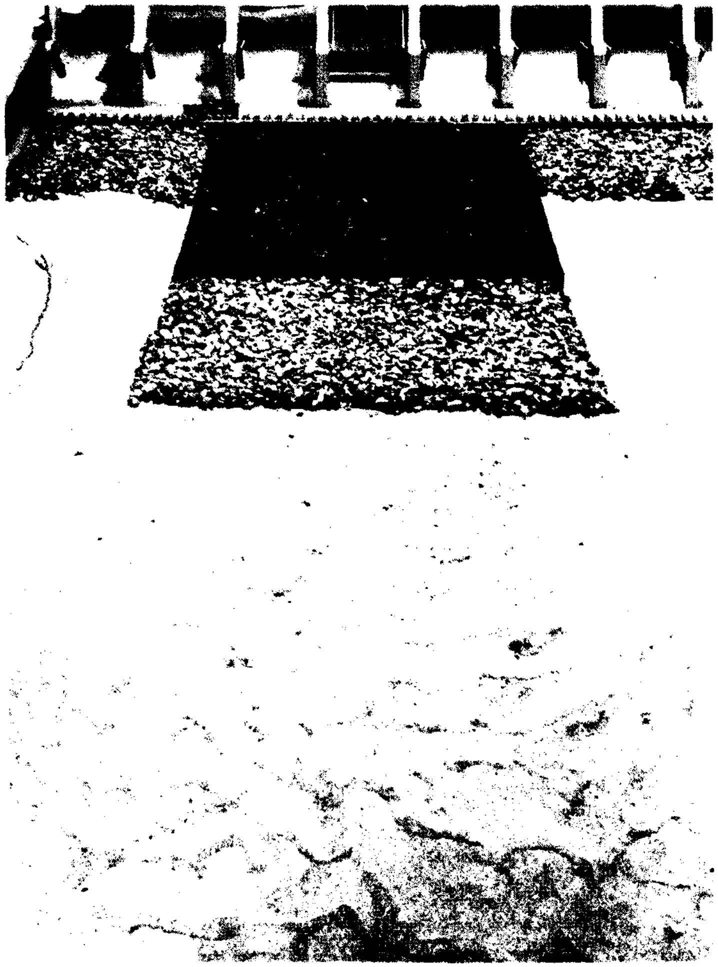


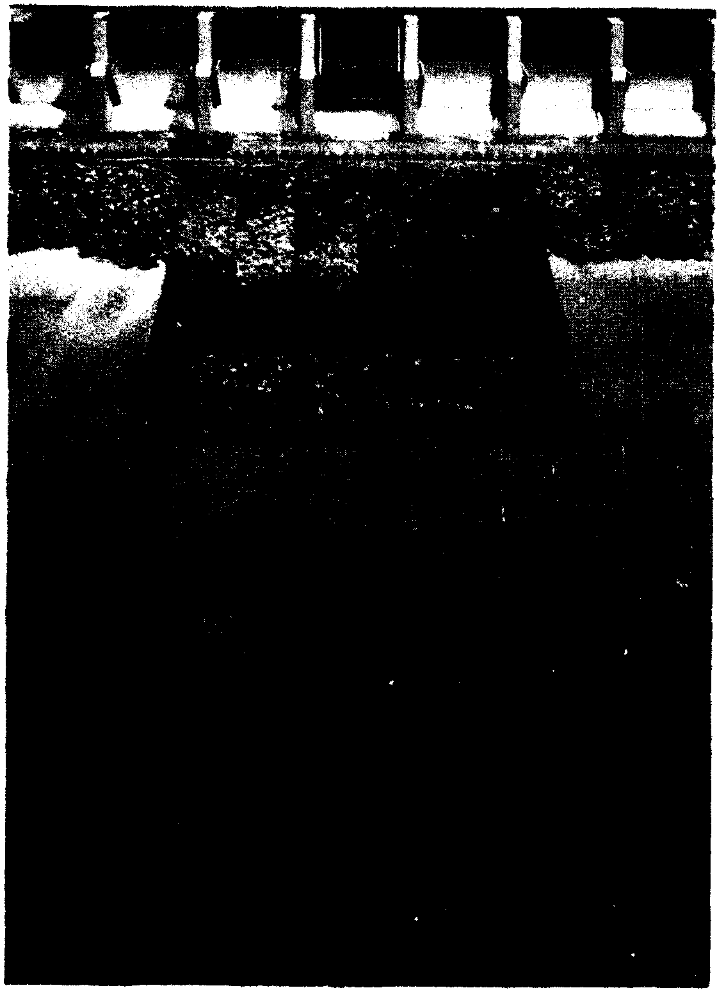
Photo 11. Flow conditions with the type 7 scour protection design, normal upper pool, one gate fully open, tailwater el 112.9



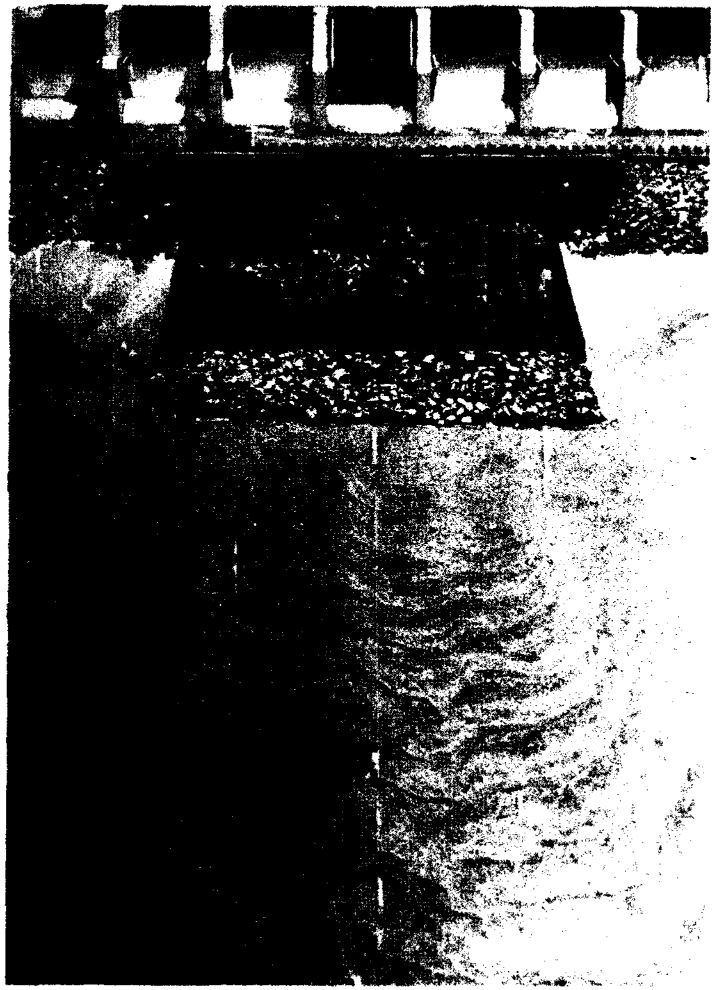
a. Blanket length 130 ft

b. Blanket length 100 ft

Photo 12. Scour in exit channel after operations with normal upper pool, one gate fully open, and tailwater 113, for various lengths of Riprap No. 7 placed downstream of barges (Sheet 1 of 3)

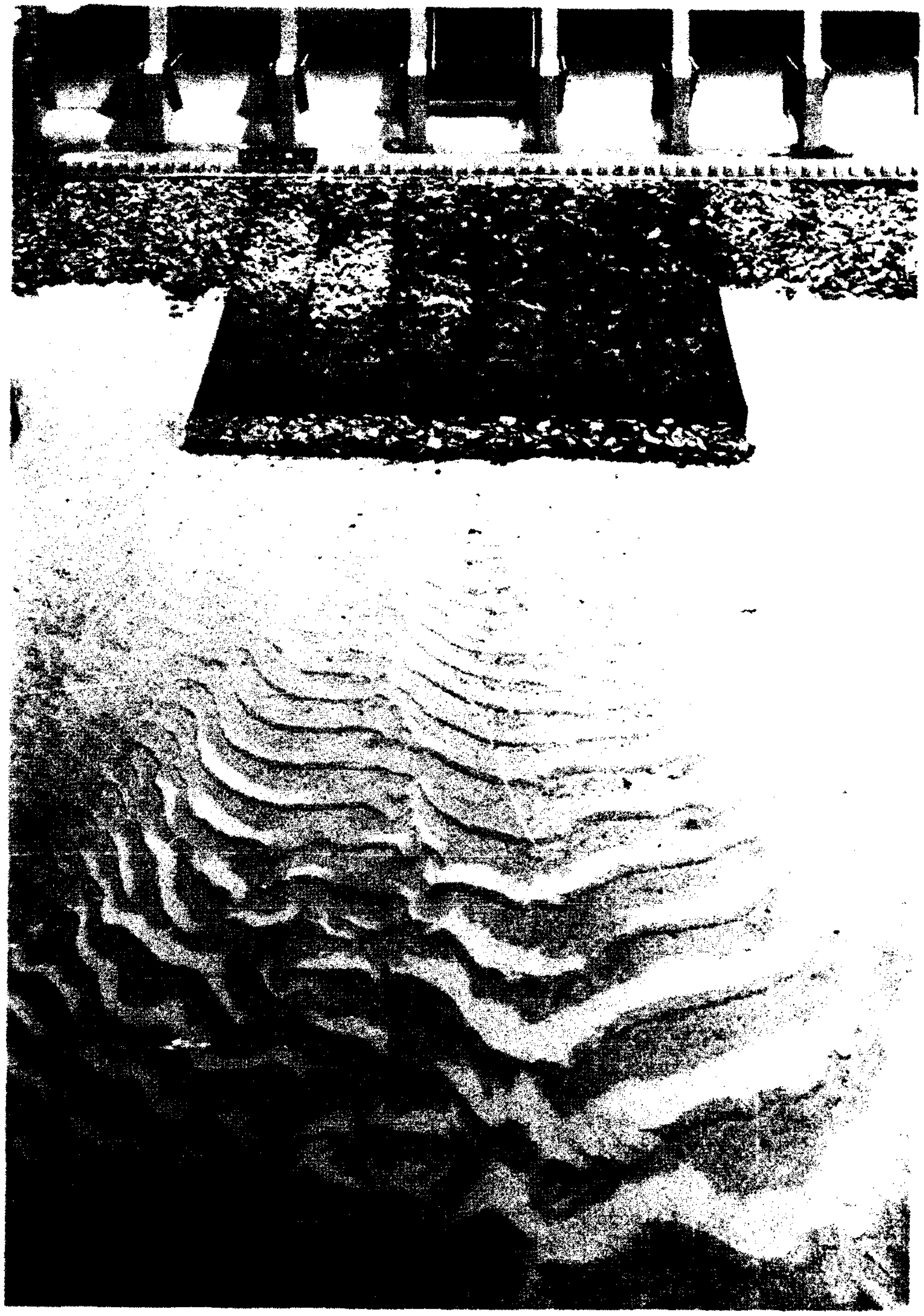


c. Blanket length 70 ft



d. Blanket length 50 ft

Photo 12. (Sheet 2 of 3)



e. Blanket length 25 ft

Photo 12. (Sheet 3 of 3)

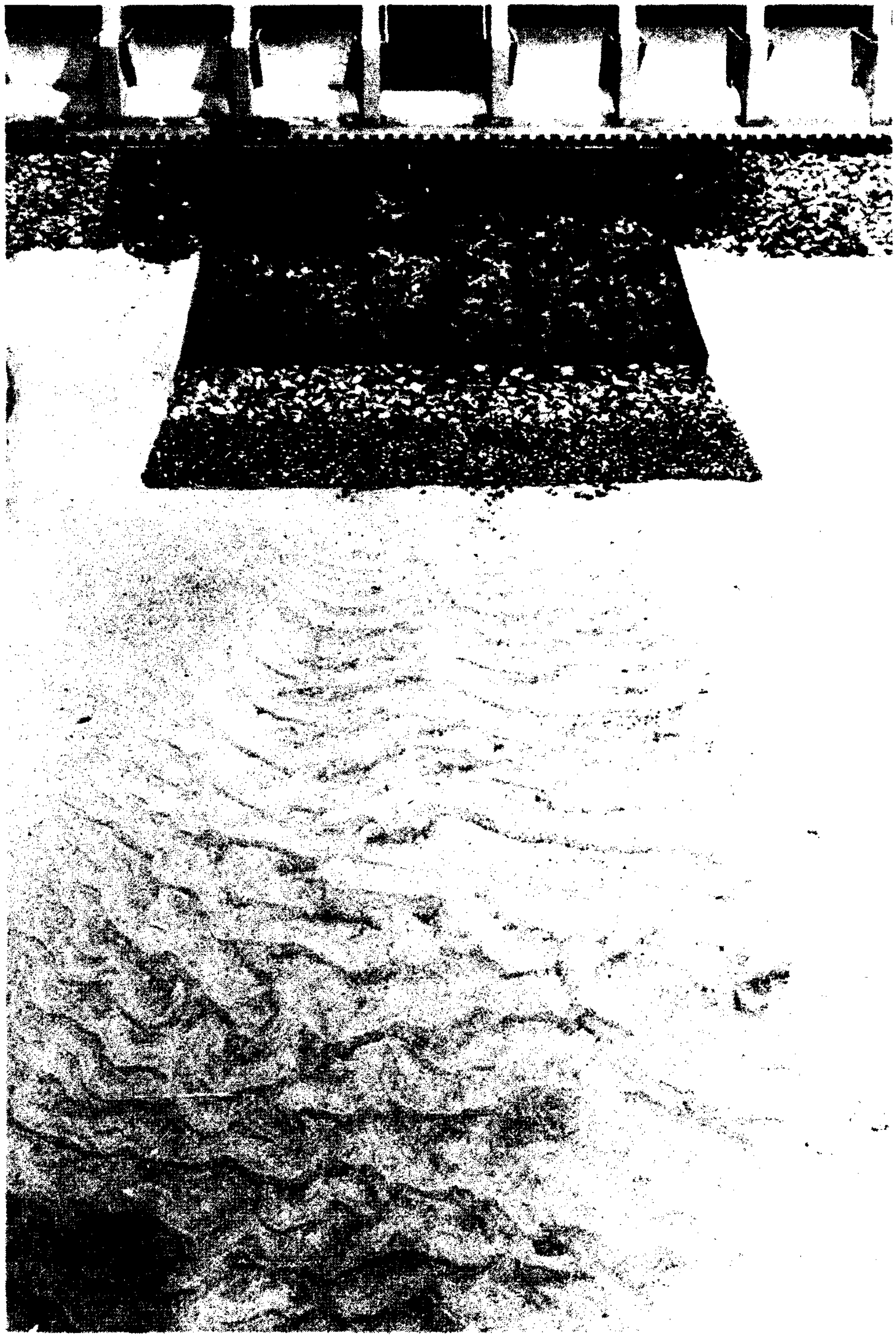
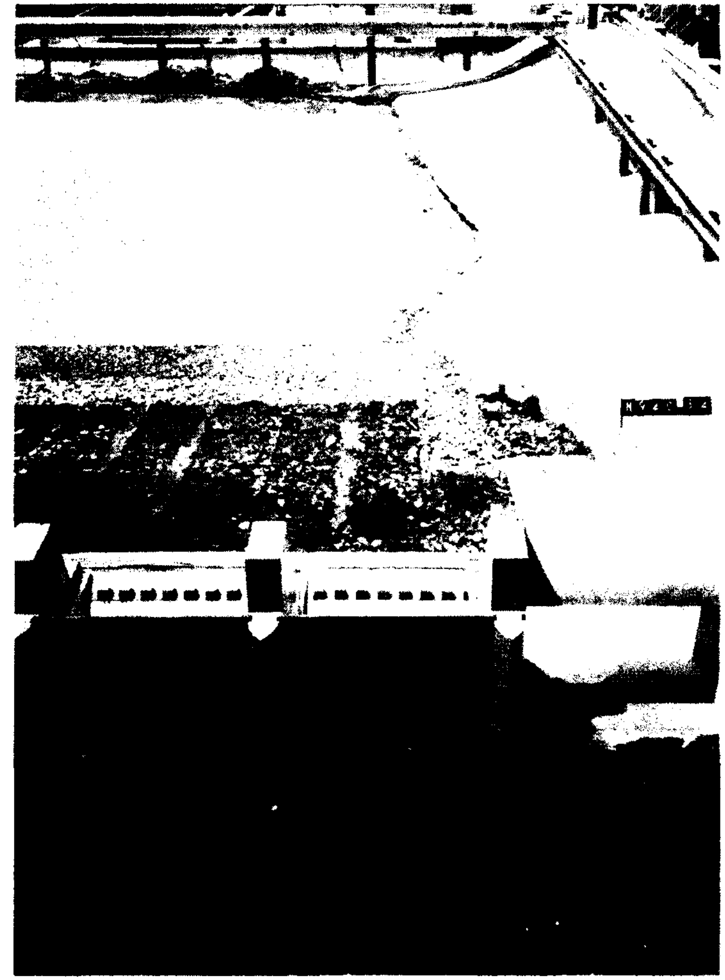


Photo 13. Type 9 scour protection design after 8 hr (prototype) of operation with normal upper pool, gate 13 fully open, and tailwater el 113

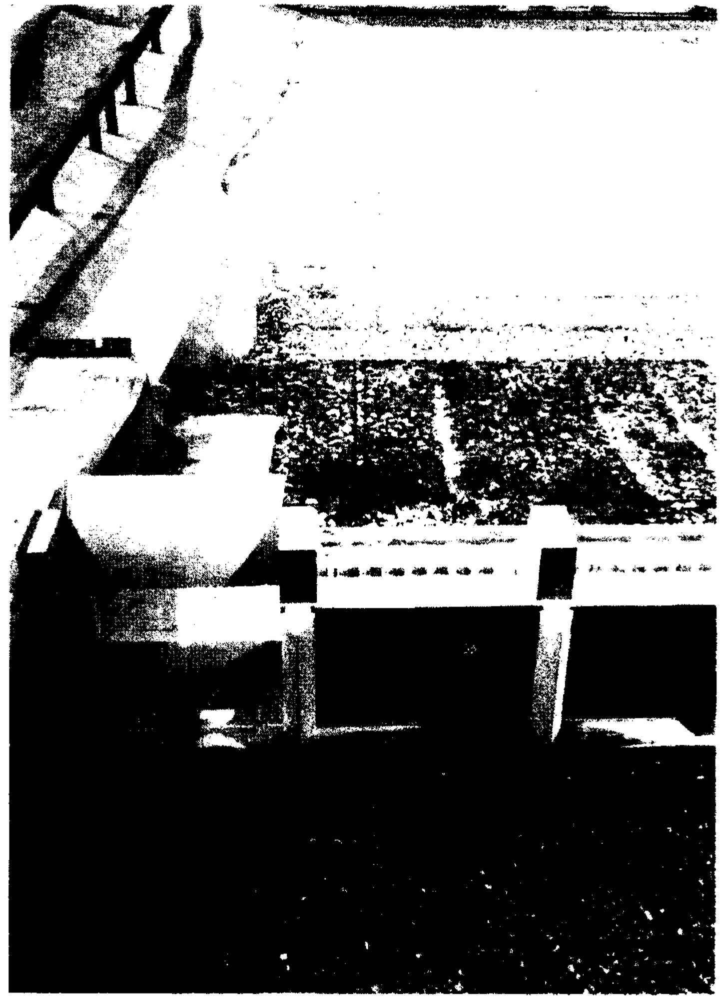
a. Looking upstream



b. Looking downstream

Photo 14. Type 9 scour protection design after 8 hr (prototype) of operation with gate 16 opened fully to the normal pool and tailwater el 113

a. Looking upstream



b. Looking downstream

Photo 15. Type 9 scour protection design after 4 hr (prototype) of operation with gate 1 opened fully to the normal upper pool and tailwater el 113

Photo 16. Failure of Riprap No. 7 on side slope

Photo 17. Failure of Riprap No. 7 on left bank

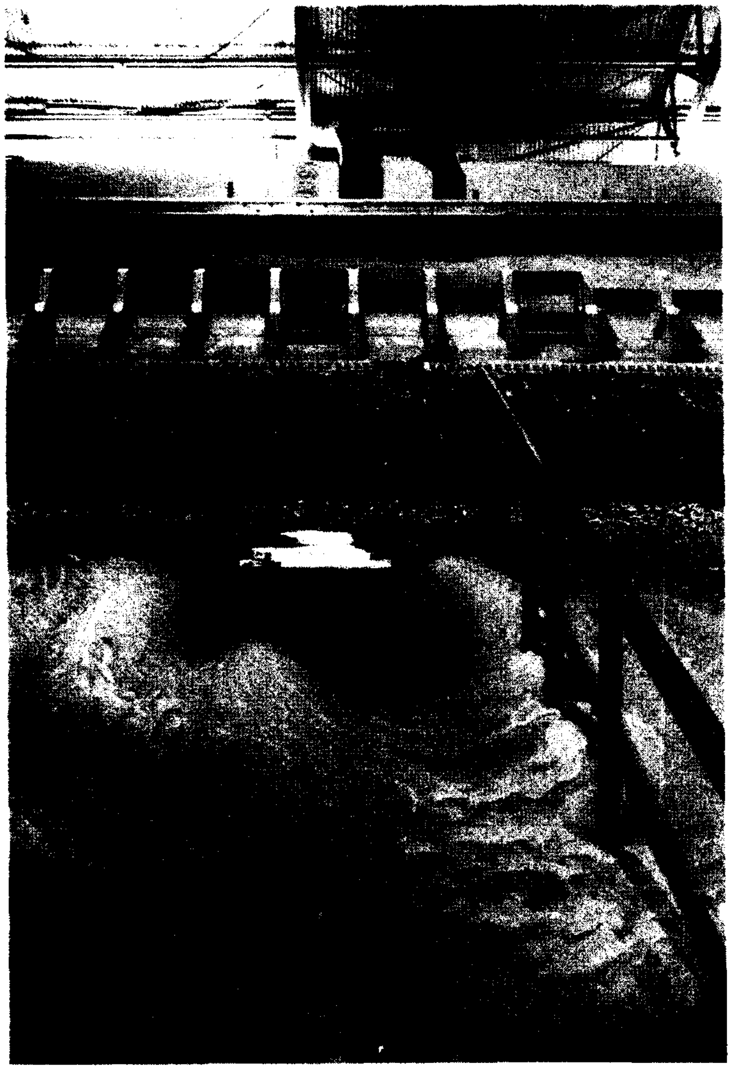


Photo 18. Failure of Riprap No. 8 downstream from a group of raised barges

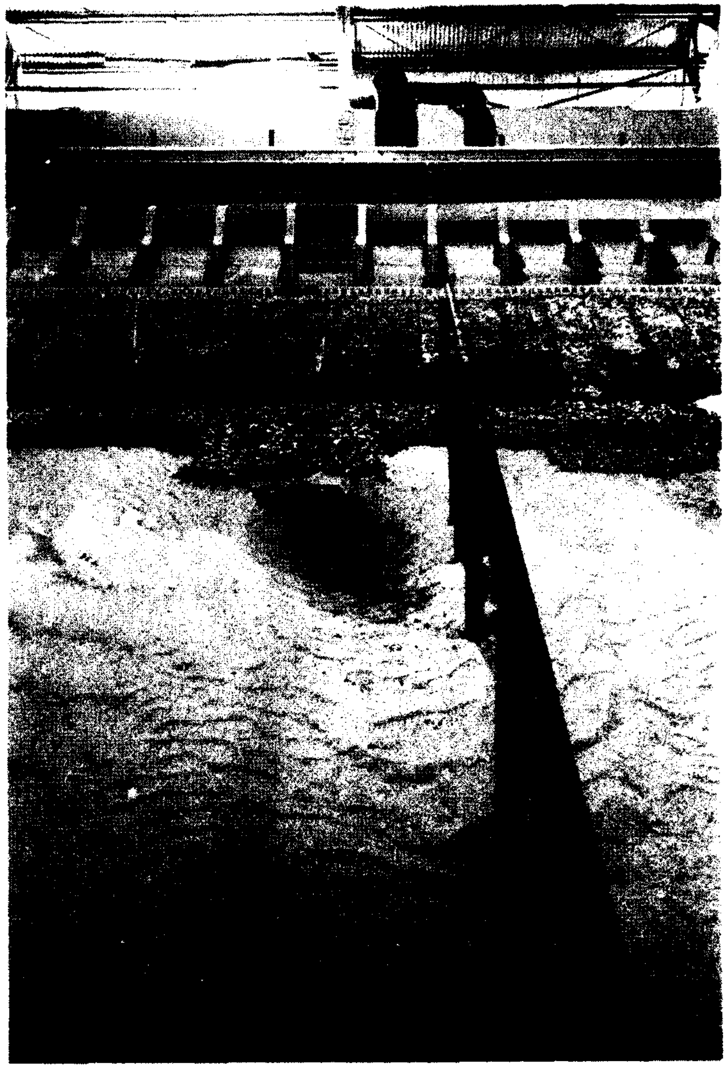


Photo 19. Failure of Riprap No. 9 placed downstream from a group of barges raised 6 ft higher than original placement

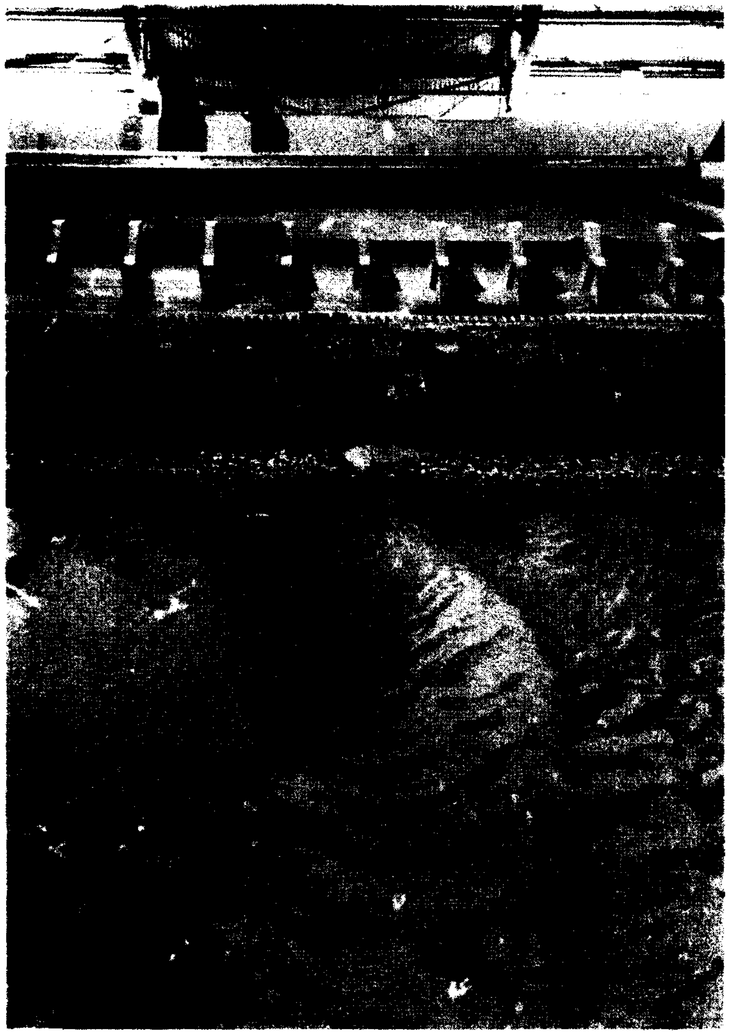


Photo 20. Results from operations with gate 7 opened fully to the normal pool and tailwater el 135. Note stability of Riprap No. 8

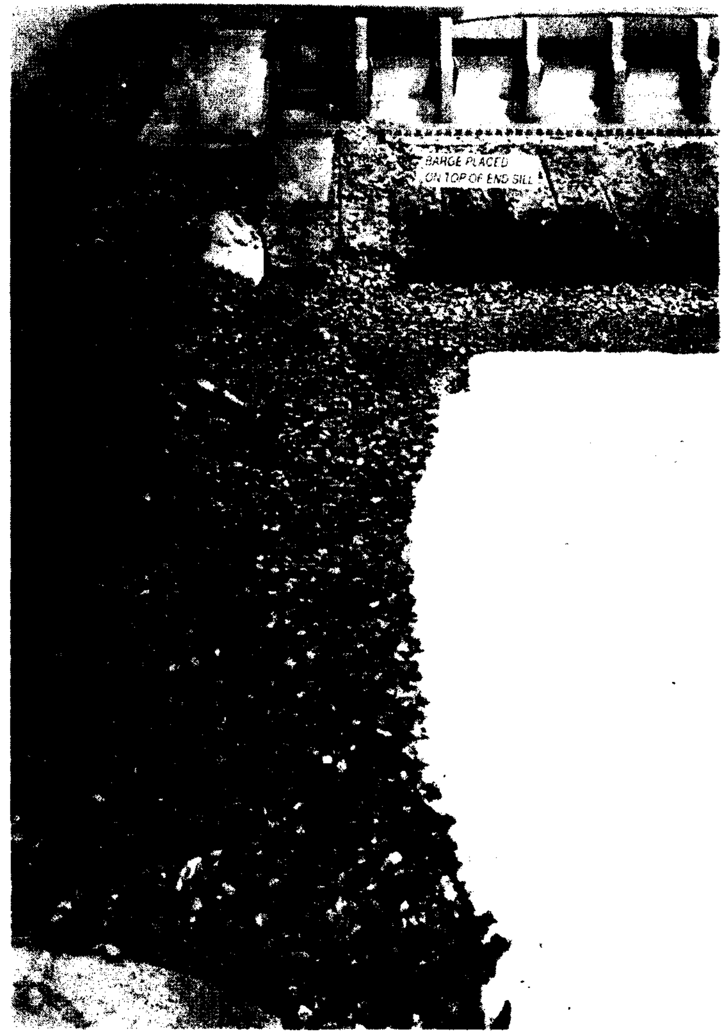
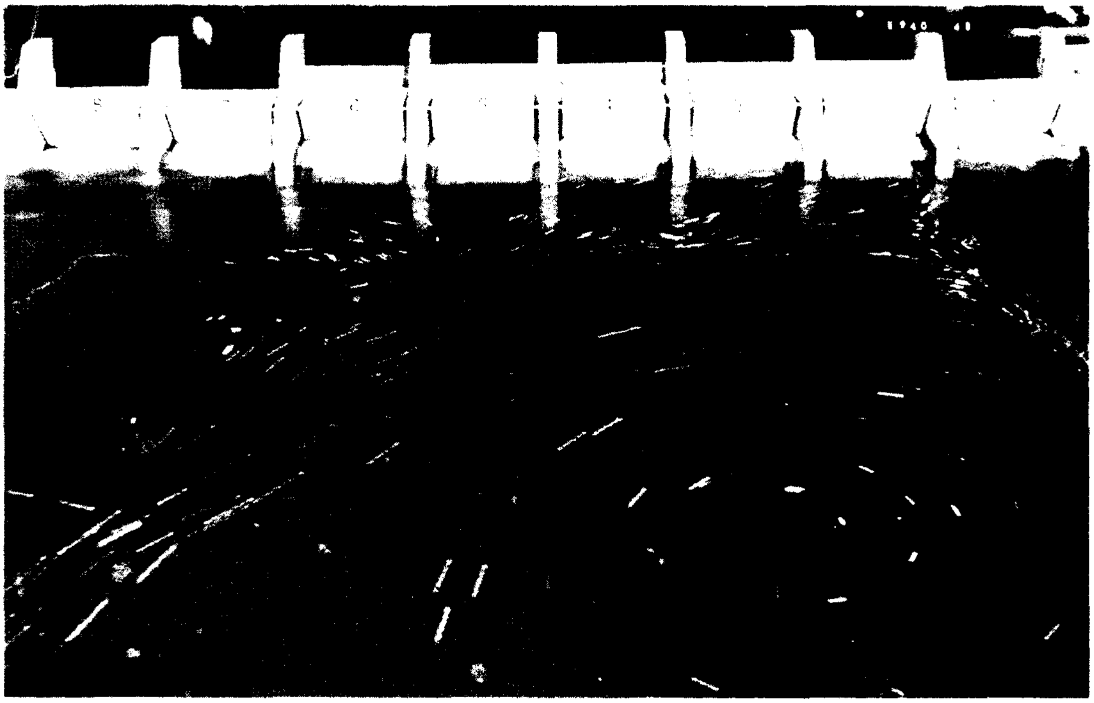
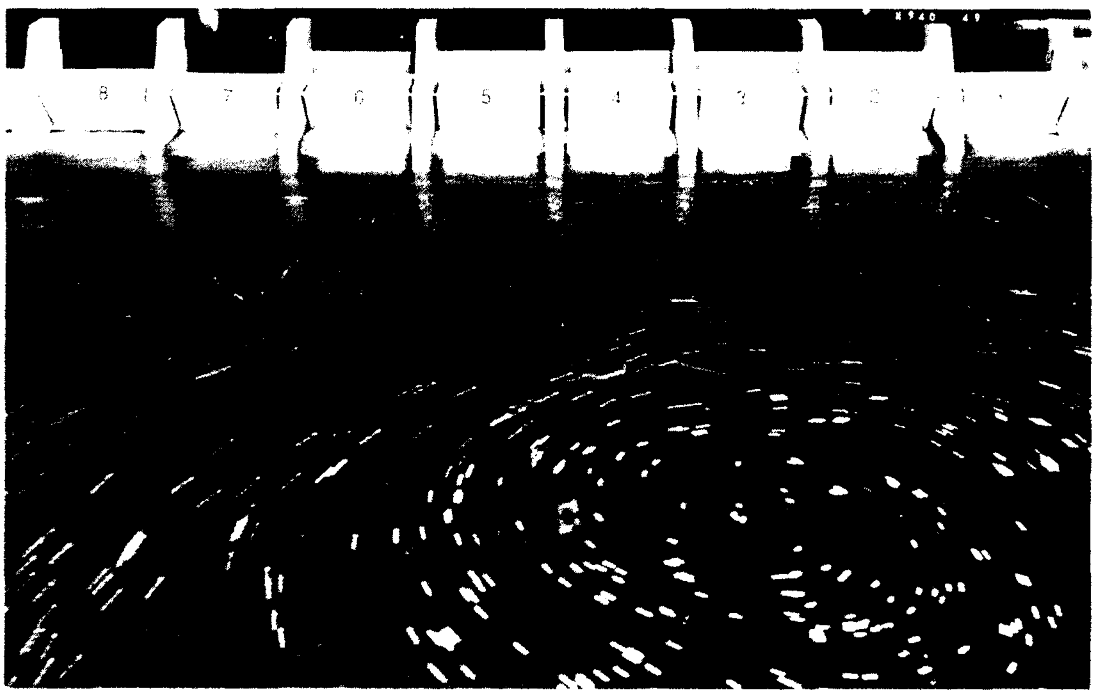


Photo 21. Failure of Riprap No. 7 on right bank due to barge on end sill

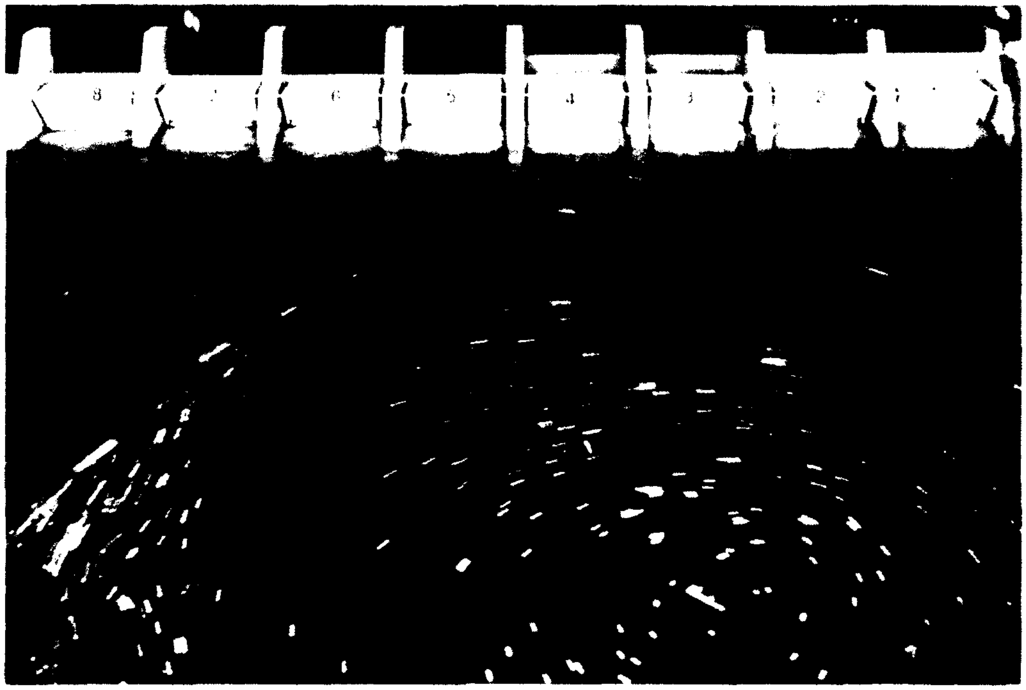


a. Tailwater el 141.2

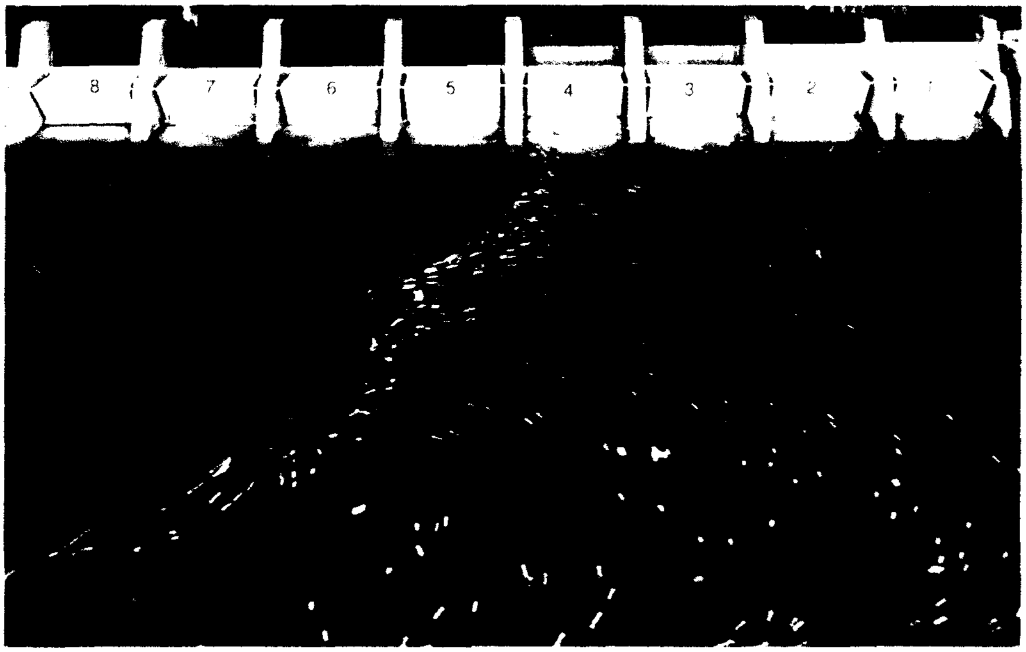


b. Tailwater el 138.5

Photo 22. Flow conditions with gates 2-6 closed, a discharge of 50,000 cfs, and pool el 162

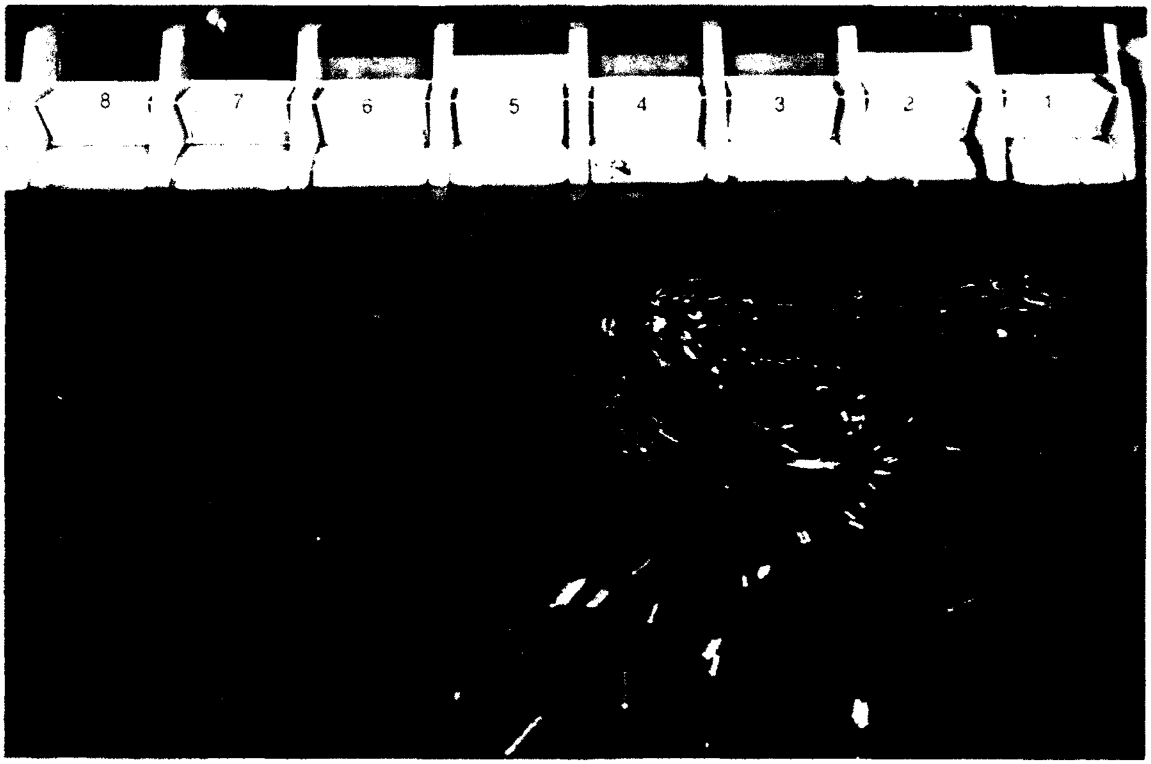


a. Tailwater el 141.2

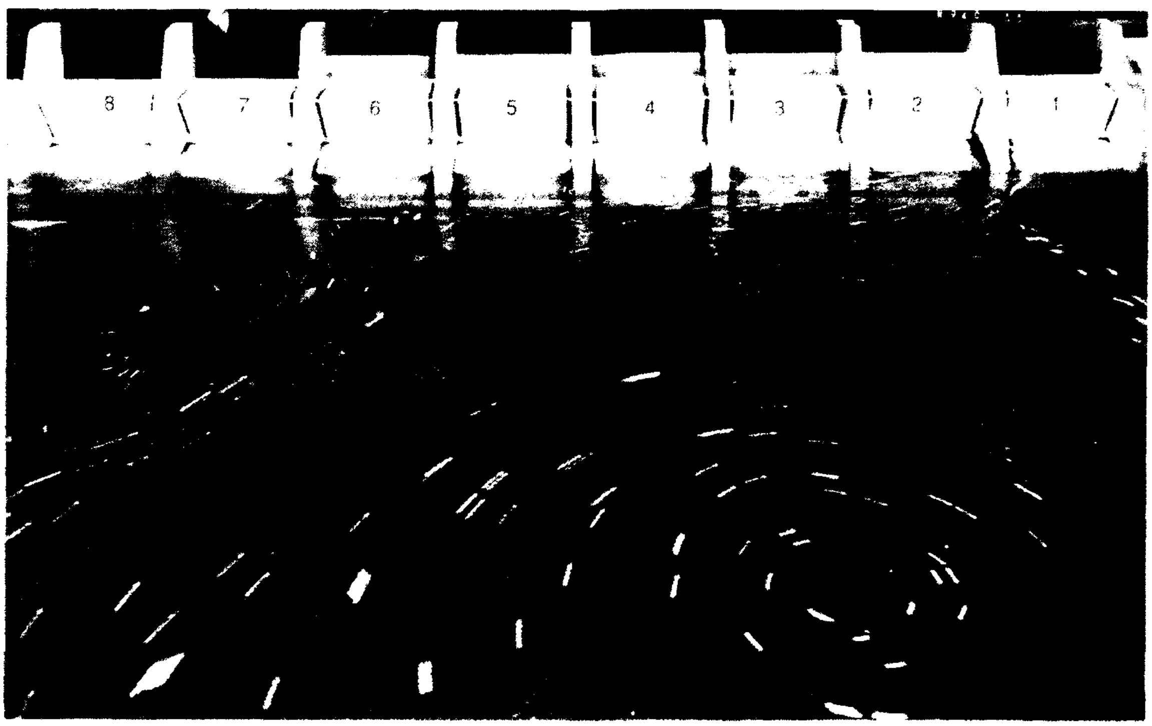


b. Tailwater el 138.5

Photo 23. Flow conditions with gates 1-4 closed, discharge of 50,000 cfs, and a pool el of 162

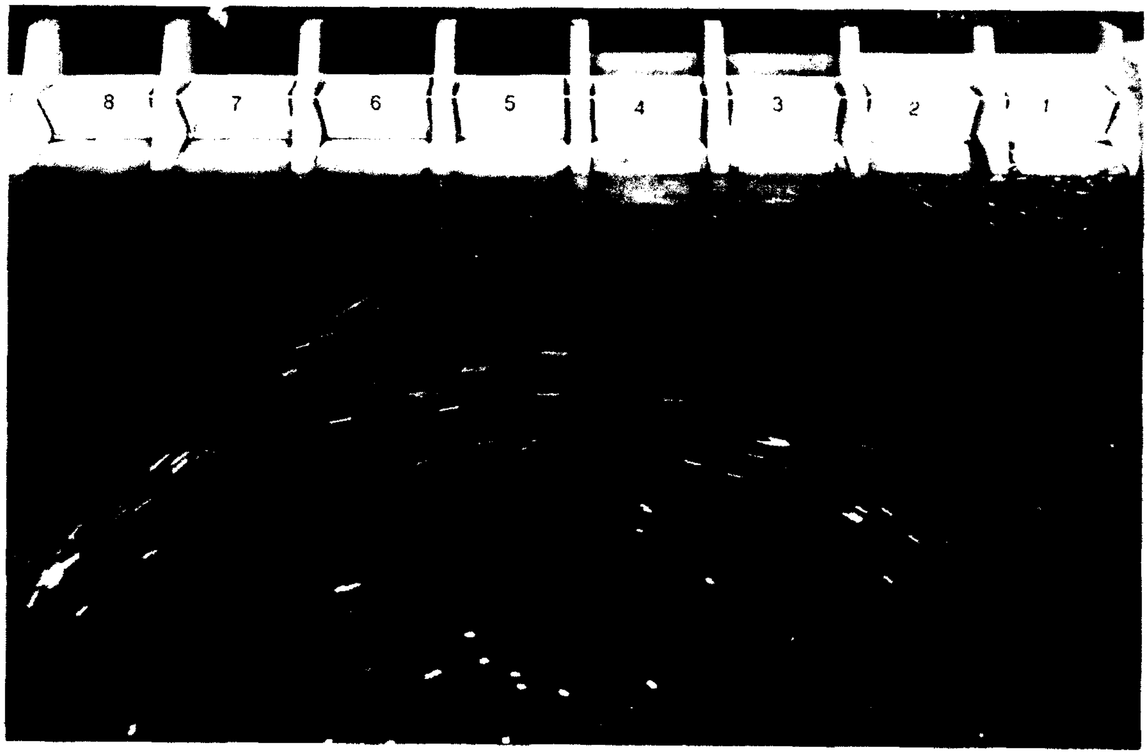


a. Tailwater el 131.0

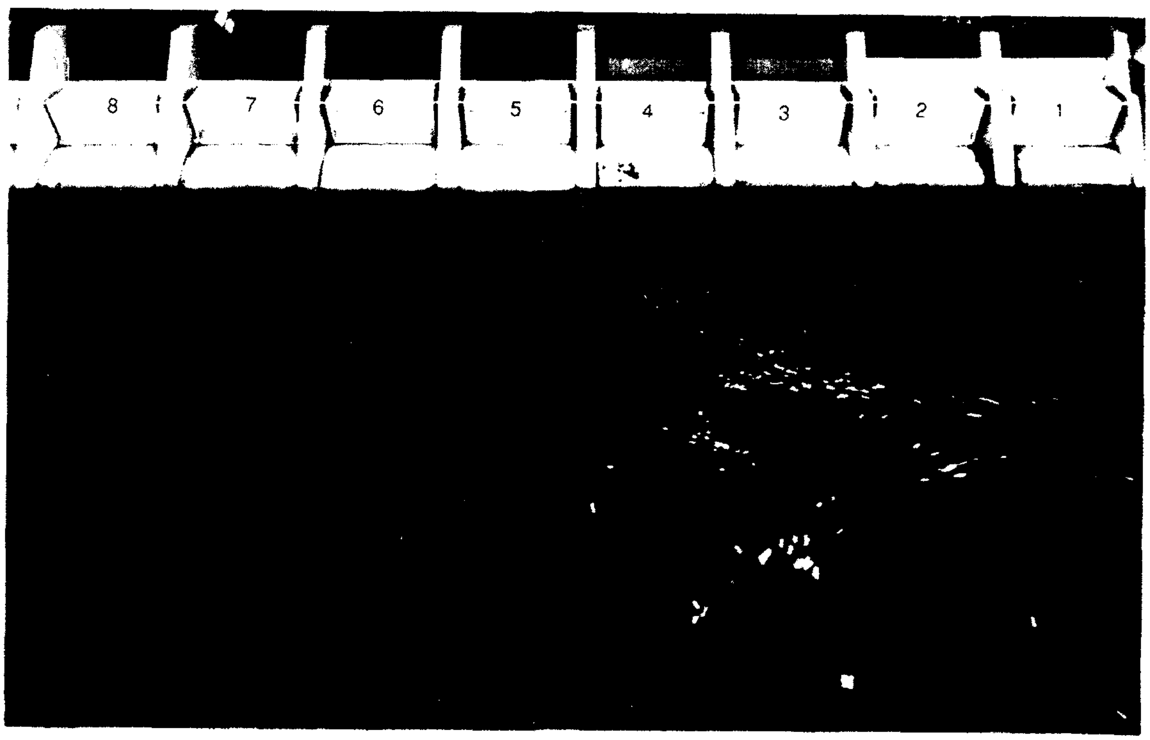


b. Tailwater el 123.0

Photo 24. Flow conditions with gates 2-6 closed, a discharge of 15,000 cfs, and pool el 162



a. Tailwater el 131.0



b. Tailwater el 123.0

Photo 25. Flow conditions with gates 1-4 closed, discharge of 15,000 cfs, and pool el 162

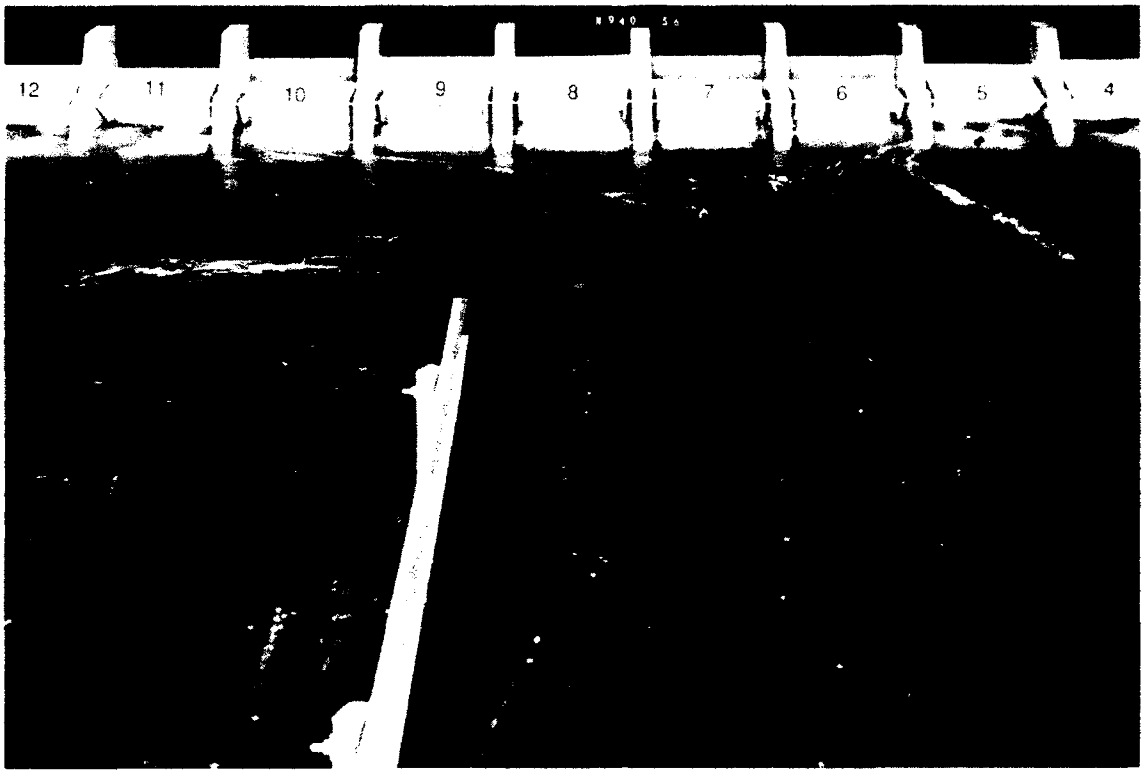
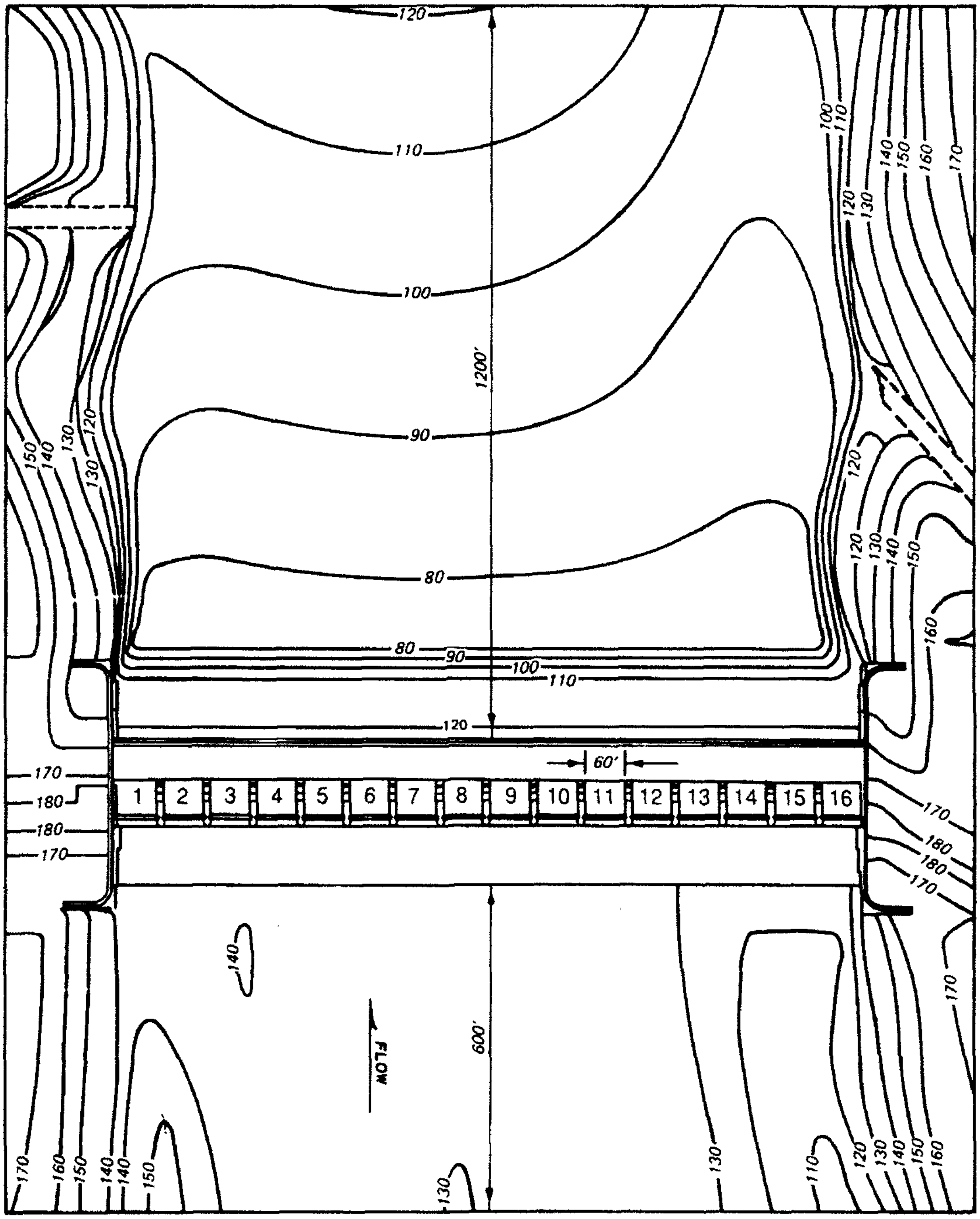
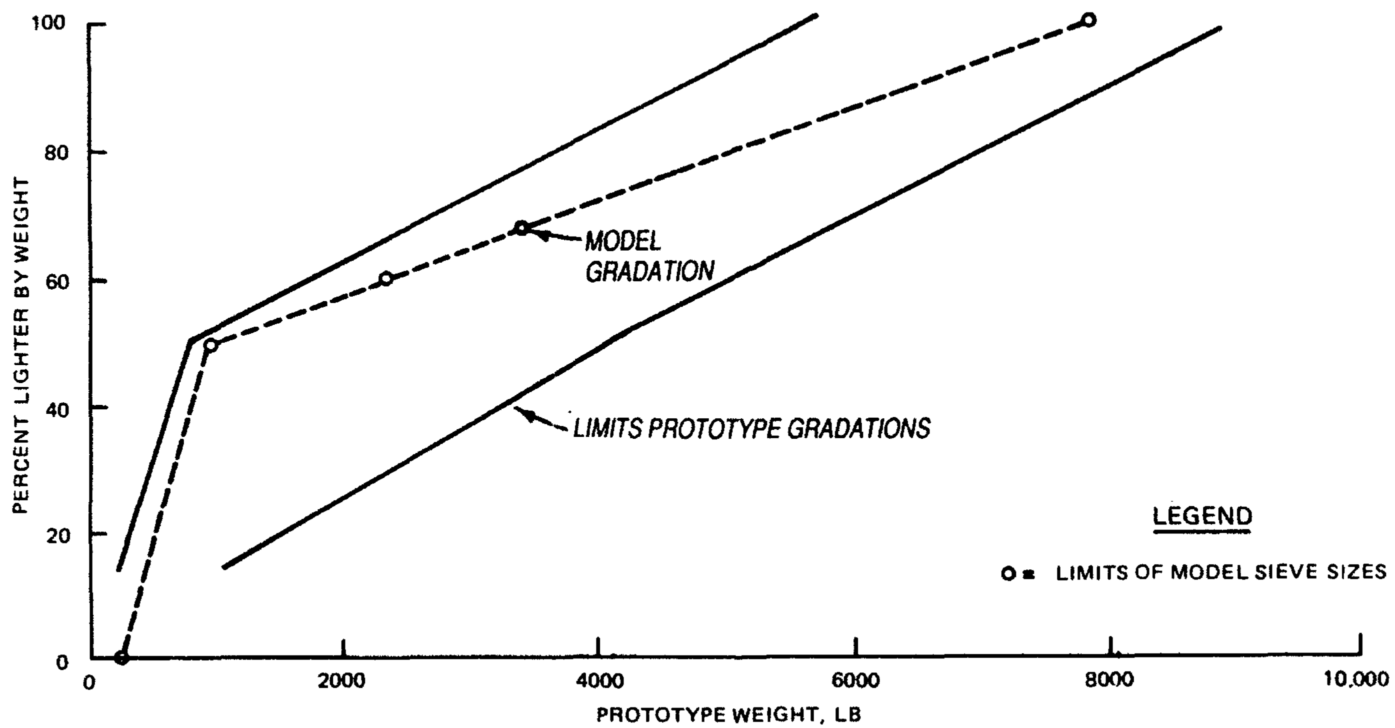


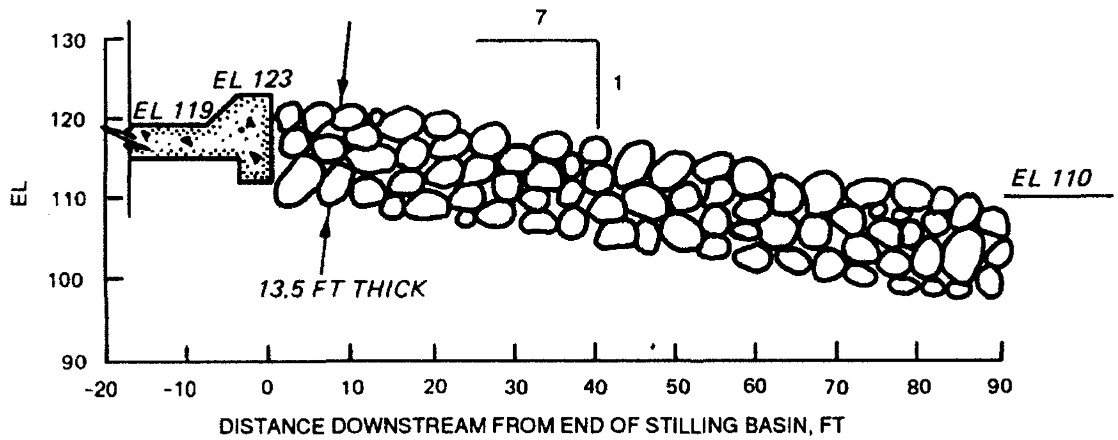
Photo 26. Flow conditions with gates 6-10 closed, discharge of 112,600 cfs, pool el 164, and tailwater el 150



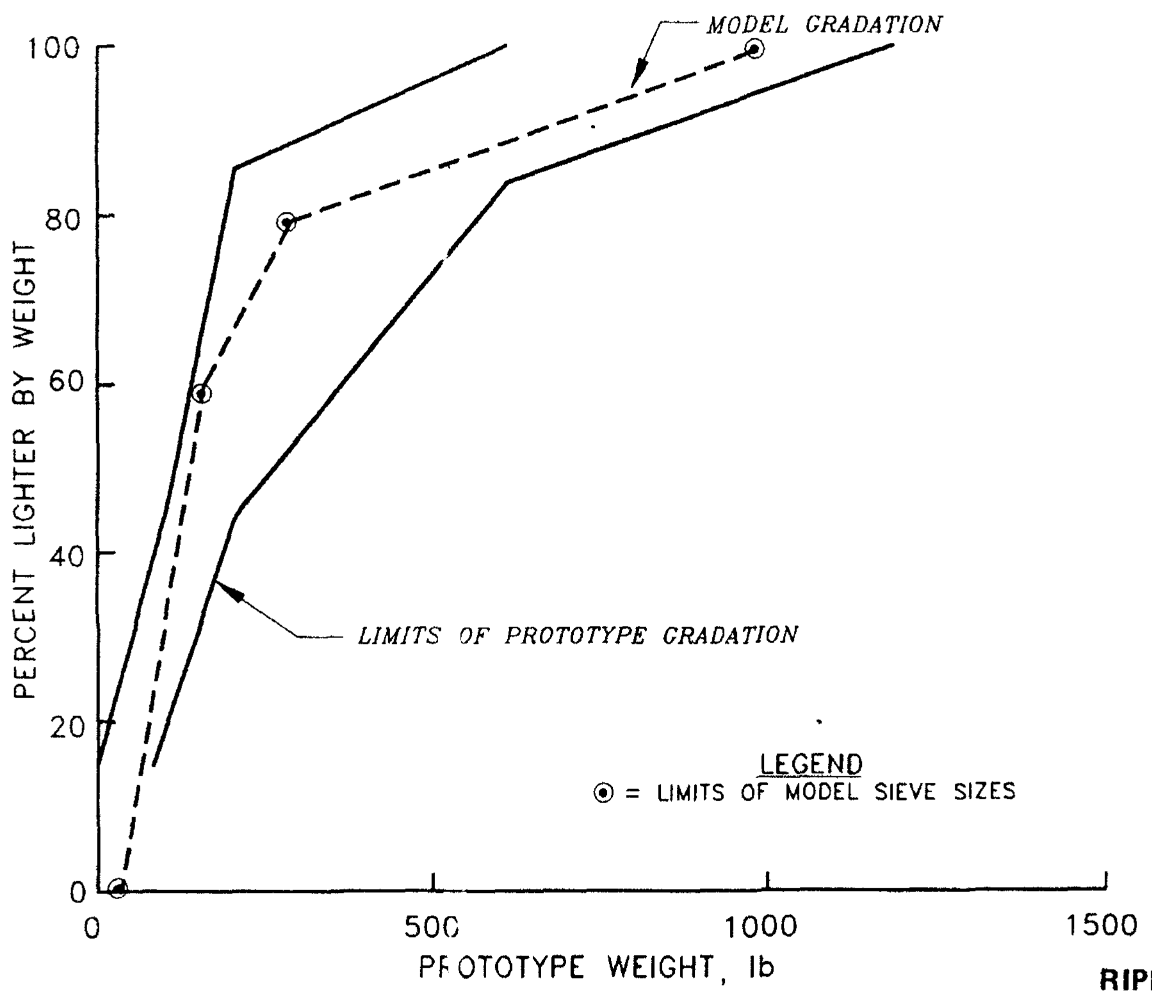
MODEL LAYOUT



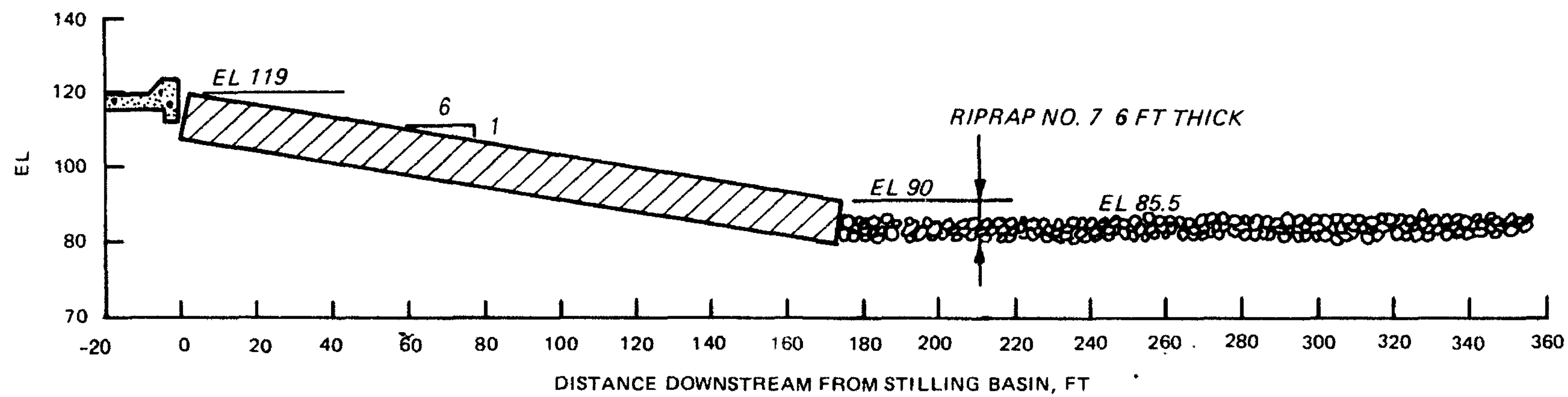
RIPRAP NO. 7 GRADATION
$D_{50(MAX)}$ = 43.5 IN.



RIPRAP NO. 7 PLACEMENT

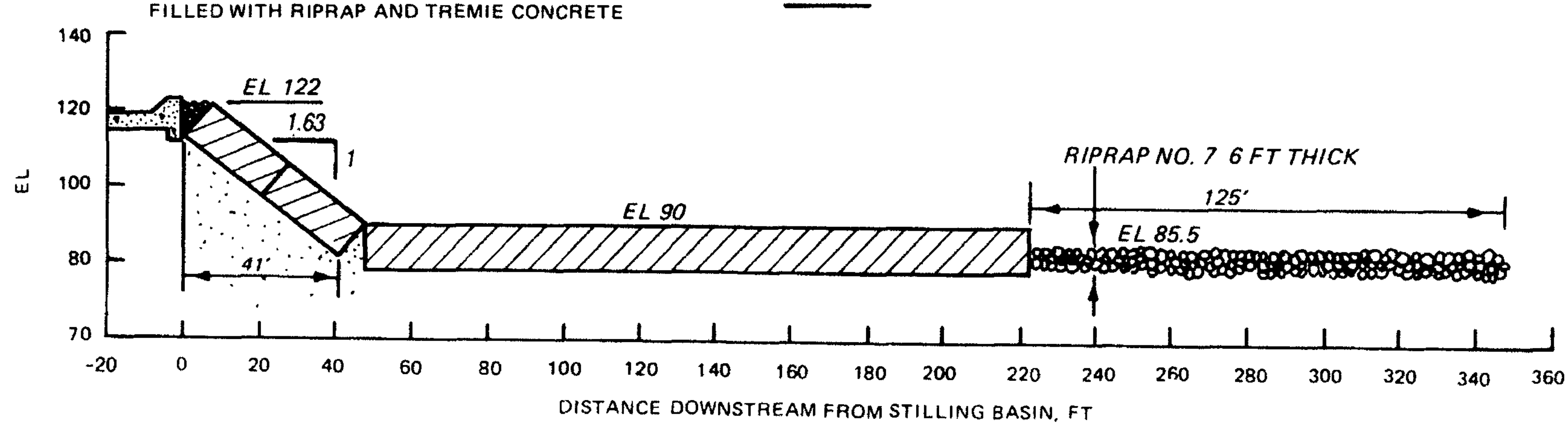


RIPRAP NO. 5 GRADATION
BLANKET THICKNESS = 36 IN.
D_{50} (MAX) = 17 IN.



NOTE: BARGES ARE 12 FT BY 26 FT BY 175 FT
FILLED WITH RIPRAP AND TREMIE CONCRETE

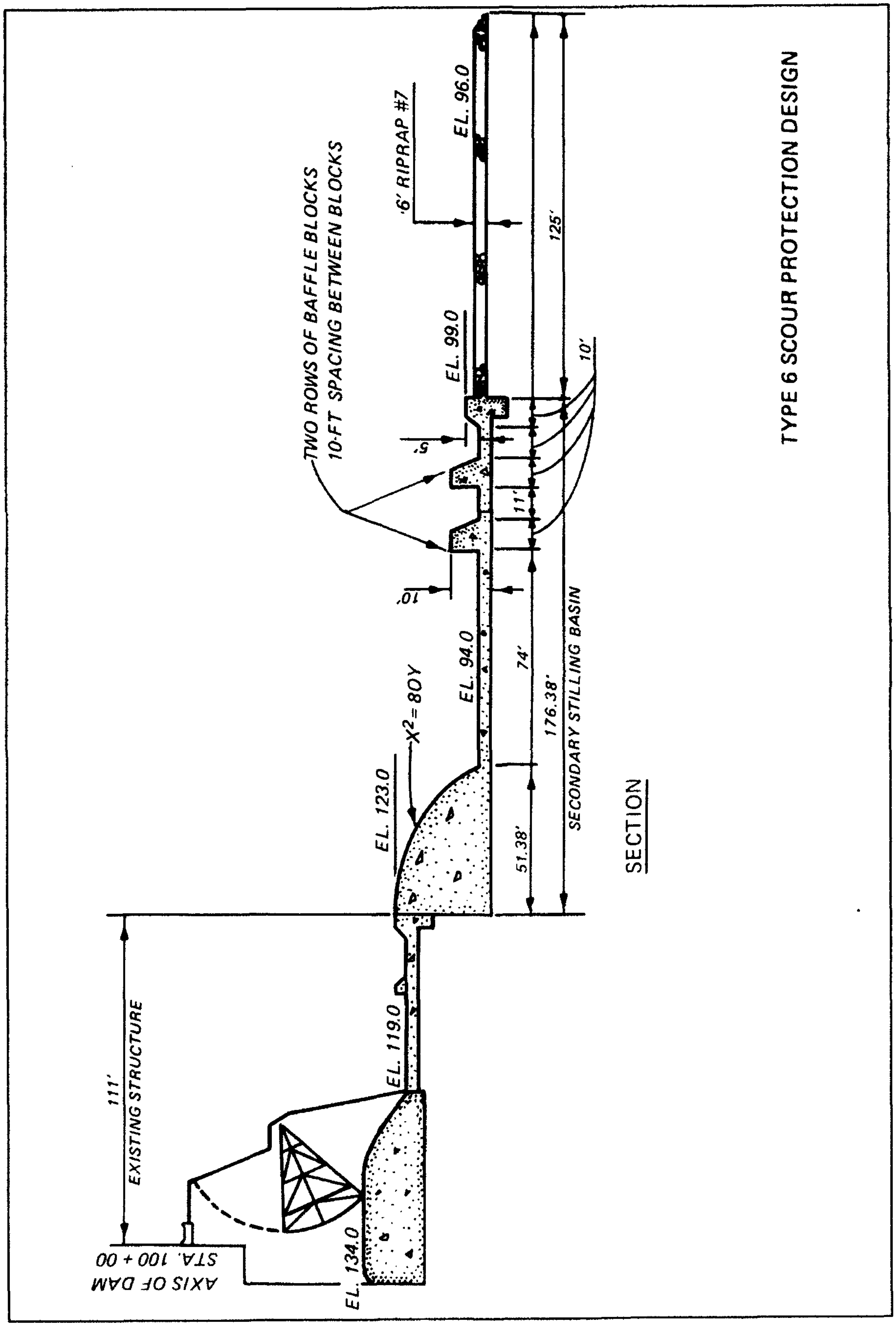
TYPE 4



TYPE 3

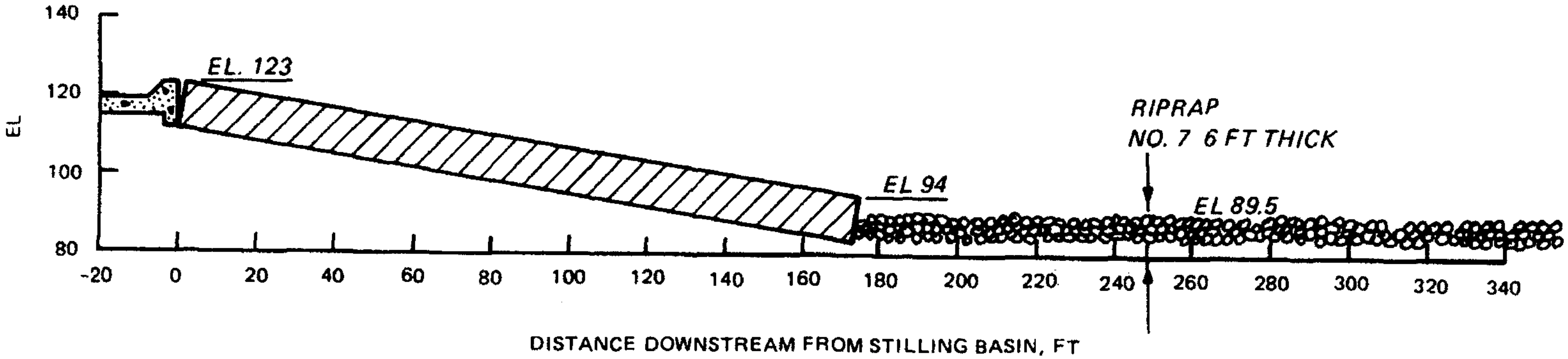
SCOUR PROTECTION DESIGN

TYPES 3 AND 4



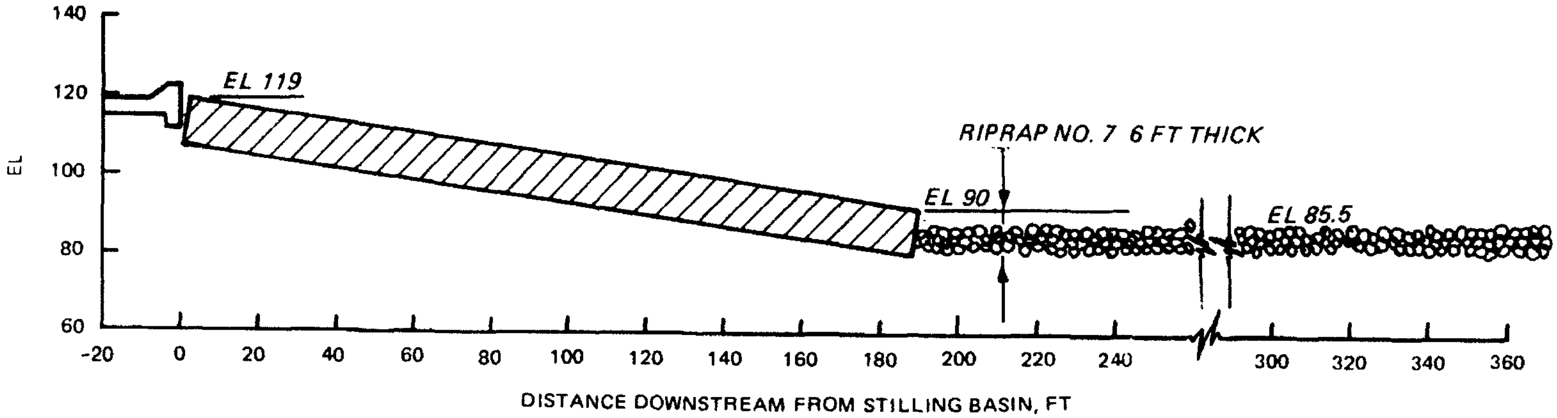
TYPE 6 SCOUR PROTECTION DESIGN

PLATE 6



TYPE 7

NOTE: BARGES ARE 12 FT BY 26 FT BY 175 FT
FILLED WITH RIPRAP AND TREMIE CONCRETE



TYPE 8

NOTE: BARGES ARE 12 FT BY 35 FT BY 190 FT
FILLED WITH RIPRAP AND TREMIE CONCRETE

SCOUR PROTECTION DESIGN
TYPES 7 AND 8

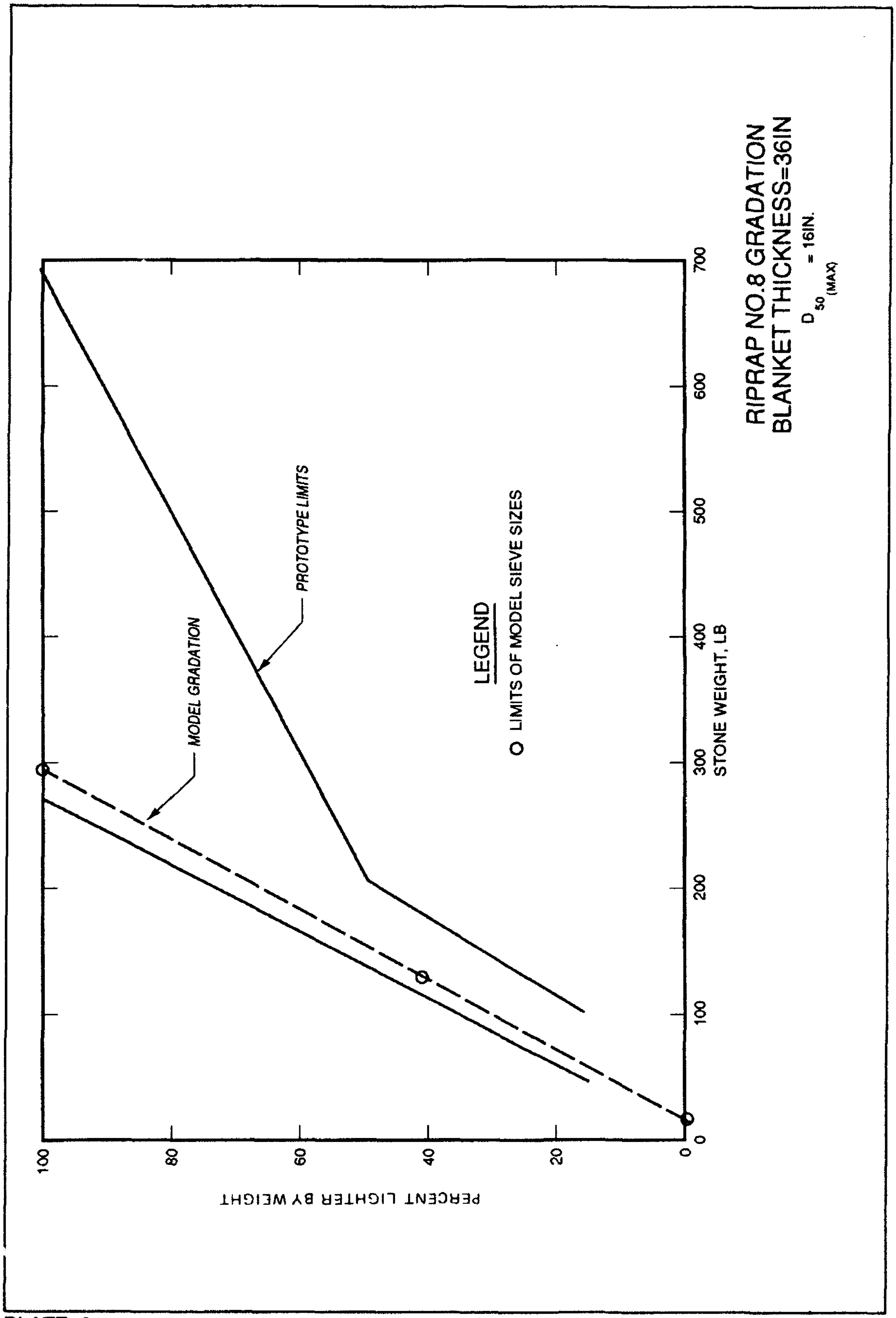
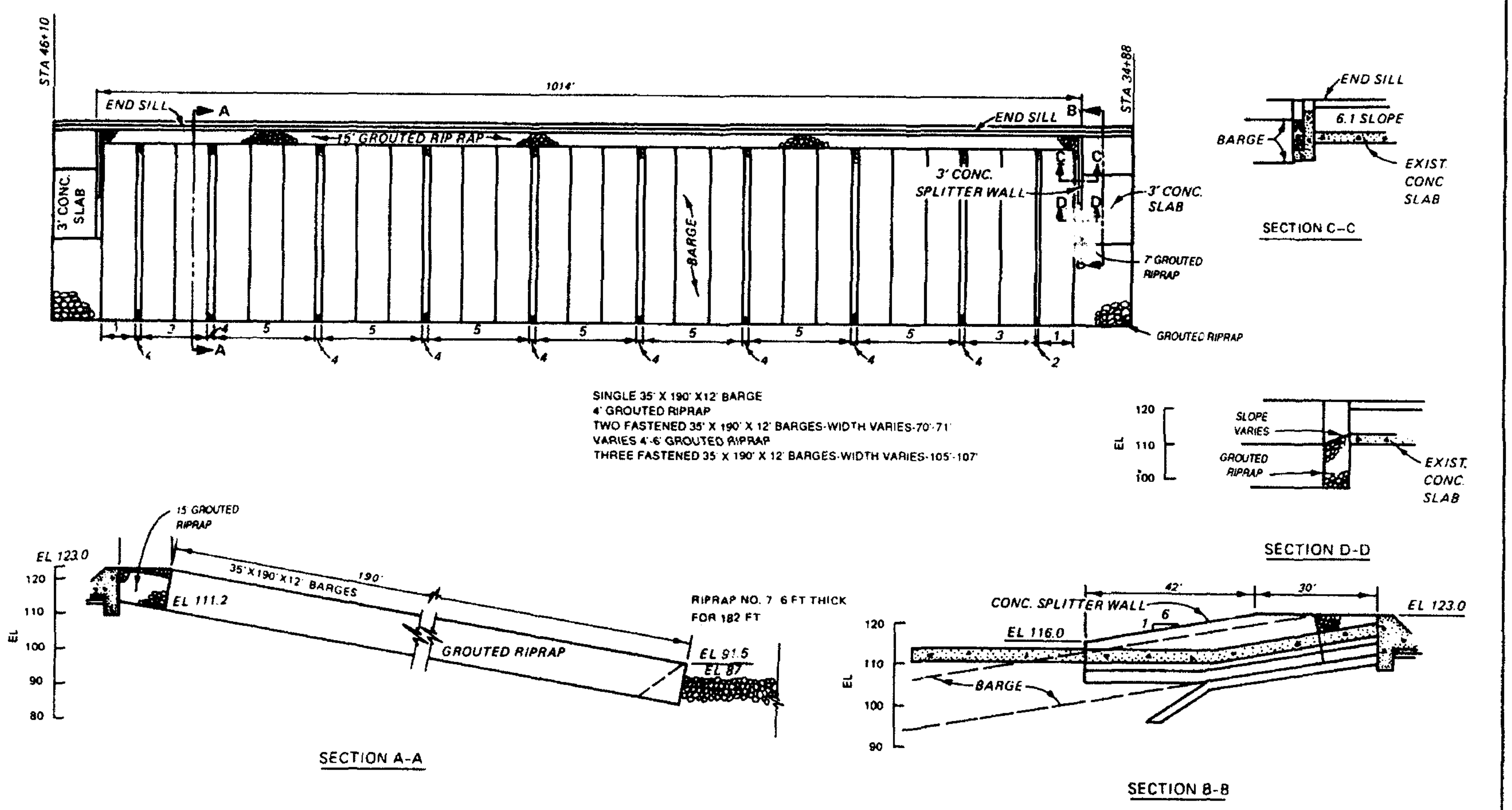
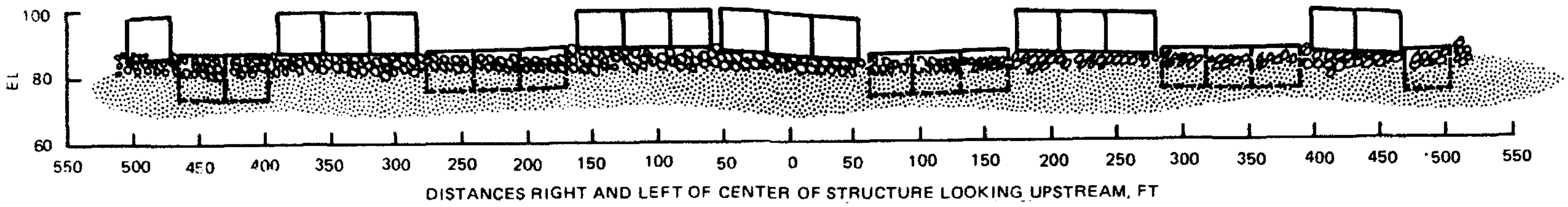

RIPRAP NO.8 GRADATION
BLANKET THICKNESS=36IN
$D_{50_{(MAX)}} = 16IN.$
MODEL GRADATION
PROTOTYPE LIMITS
LEGEND
O LIMITS OF MODEL SIEVE SIZES
PERCENT LIGHTER BY WEIGHT
STONE WEIGHT, LB
0
100
200
300
400
500
600
700
20
40
60
80
100

PLATE 8

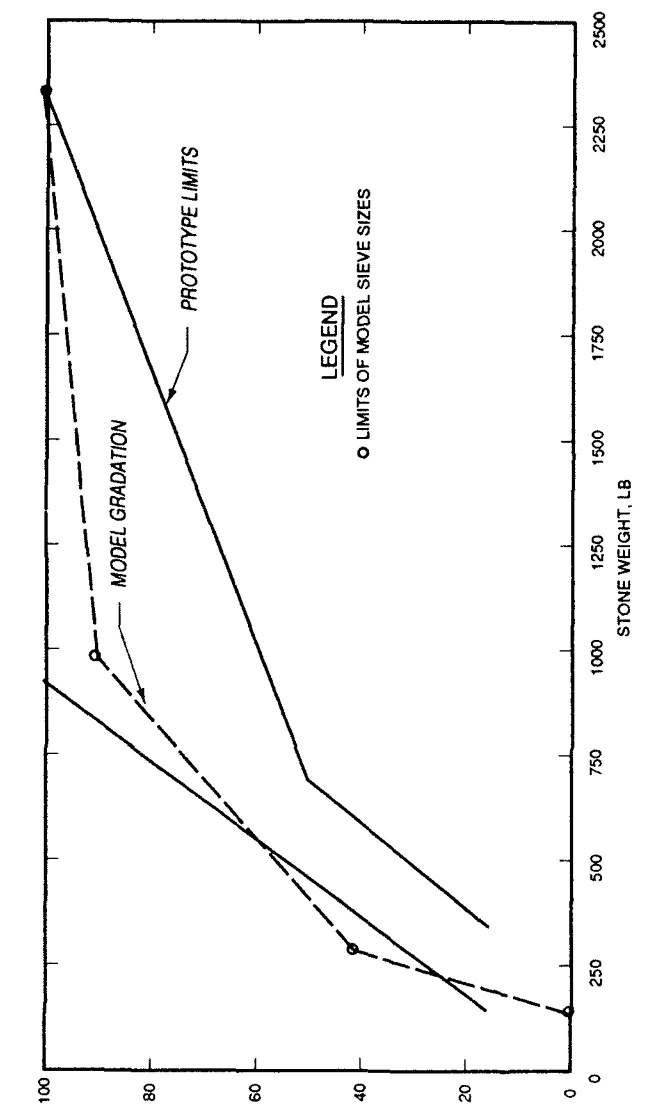


BARGE PLACEMENT IN TYPE 9
SCOUR PROTECTION PLAN



NOTE: VIEW IS LOOKING UPSTREAM AT DOWNSTREAM END OF BARGE

STAGGERED PLACEMENT OF BARGES WITH
TYPE 9 SCOUR PROTECTION DESIGN



RIPRAP NO.9 GRADATION
BLANKET THICKNESS=54IN.
$D_{50_{(MAX)}} = 24$ IN

REPORT DOCUMENTATION PAGE

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Hite, John E., Jr.

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3909 Halls Ferry Road, Vicksburg, MS
39180-6199

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12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Tests were conducted on a 1:36-scale model of Dam No. 2, Arkansas River, to determine a method to prevent additional scour upstream and downstream from the structure and protect these areas from flow conditions resulting from gate misoperation, vandalism, debris passage, and navigation accidents. The model reproduced 600 ft of topography upstream from the dam, the entire spillway and stilling basin, the proposed scour protection material, and approximately a 1,200-ft length of the channel downstream from the stilling basin.

A navigation accident in December of 1982 severely damaged the scour protection upstream and downstream from the dam. Initial model tests were conducted to determine the degree of scour protection provided by the riprap used to repair the damaged areas after the accident. Tests were then conducted to develop scour protection for flow conditions resulting from operations with a single gate fully open, the normal upper pool, elevation (el) 162 ft referred to the National Geodetic Vertical Datum, and the minimum anticipated tailwater, el 113. A secondary stilling basin that performed satisfactorily was developed for these flow conditions, but construction was not feasible. There was concern that the project could not be dewatered, and the method of scour protection determined from the model would have to be constructed underwater. (Continued)

14. SUBJECT TERMS
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Navigation dam
Riprap
Scour protection

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13. (Concluded).

A scour protection plan was developed for the flow conditions stated previously that consisted of sunken barges, grouted riprap (riprap with tremie concrete placed in the voids), and graded riprap. The barges were filled with grouted riprap and placed beginning 15 ft downstream from the end of the existing stilling basin and sloped downward on a 1V on 6H slope. The area between the end of the stilling basin and the barges was backfilled with riprap and grouted, and a horizontal blanket of graded riprap was placed downstream from the barges for a distance of 100 ft.